The Effects of Aeration on the Rearing of Summer Chinook Fry *(Oncorhynchus tshawytscha)* at the Puntledge Hatchery

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ABSTRACT

Wright, P.B., and W.E. McLean. 1985. The effects of aeration on the rearing of summer chinook fry (Oncorhynchus tshawytscha) at the Puntledge Hatchery. Can. Tech. Rep. Fish. Aquat. Sci. 1390: 59 p.

High mortality rates have occurred in summer chinook fry (Oncorhynchus tshawytscha) reared at the Puntledge Hatchery. The mortalities were concurrent with increased gas supersaturation levels which occur during April and May in the Puntledge River. In the spring of 1983, tests were performed to assess the advantages of aerating the water supply. Packed column aerators were installed and the effects on fry rearing were measured over the 122-day rearing period. Aeration reduced Total Gas Pressure (TGP) from an average of 105.1% (nitrogen = 107.0%) to 101.1% (nitrogen = 101.8%). Although mortalities in both treatments were low, the troughs with aeration experienced less than half the mortality of the control troughs (1.6% for the aerated troughs vs 4.1% for the control troughs). These results have provided valuable insight into the effects of long term exposure to low level gas supersaturation. Subtle differences in condition coefficients, seawater tolerance, liver histopathology and behaviour were measured. However, because characteristic mortality patterns of the past did not recur in 1983, it remains unclear whether installation of aerators would provide sufficient benefits to the chinook salmon rearing program at the Puntledge Hatchery.

Key words: chinook salmon, gas bubble disease, nitrogen supersaturation, Total Gas Pressure, aeration, packed columns.

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On a observé des taux élevés de mortalité chez les alevins de saumon quinnat (Oncorhynchus tshawytscha) produits en été à la piscifacture de Puntledge. Cette mortalité concordait avec des niveaux plus élevés de supersaturation gazeuse qui se produisent en avril et mai dans la rivière Puntledge. Au printemps 1983, on a mené de essais afin d'évaluer les avantages fournis par l'aération de l'eau d'approvisionnement. On a donc installé des colonnes d'aération garnies et quantifié les incidences sur la culture d'alevins pendant la période d'alevinage de 122 jours. L'aération a entraîné une baisse de la pression gazeuse totale (PGT), soit d'une moyenne de 105.1% (azote = 107.0%) à 101.1% (axote = 101.8%). La mortalité était faible avec les deux traitements, mais le taux dans les bassins aérés était plus de 50% inférieur à celui observé dans les bassins témoins (1.6% dans les bassins aérés contre 4.1% dans les bassins témoins). Ces résultats ont fourni des connaissances précieuses sur l'incidnence d'une exposition à une faible supersaturation gazeuse. On a quantifié les variations ténues des coefficients de condition, de la tolérance à l'eau salée, de l'histopathologie hépatique et du saumon quinnat à la piscifacture de Puntledge étant donné que les schèmes caractéristiques de mortalité observés antérieurement ne se sont pas reproduits en 1983.

Mots-clés: saumon quinnat, aéroembolisme, supersaturation en azote, pression gazeuse totale, aération, colonnes garnies.

INTRODUCTION

Dissolved gas supersaturation, since its discovery as the cause of gas bubble disease in the Columbia River system (Westgard 1964; Ebel 1969), has become the subject of extensive research (Weitkamp and Katz 1980). This condition results from gas dissolving in water under greater than atmospheric pressure; for example when water passes over dam spillways into deep basins and in the process entrains air bubbles. Supersaturation also arises from heating saturated water, which decreases gas solubility and results in excess dissolved gas levels. Thus thermal power stations, geothermal heating and solar heating can all cause gas supersaturation. This condition is thought to have caused high mortalities of juvenile salmon at some British Columbia hatcheries.

Chinook juveniles (Oncorhynchus tshawytscha) detect the presence of supersaturation, and in natural waters seek a depth where higher gas solubility, due to increased pressure, compensates for the high dissolved gas levels (Dawley et al. 1976). However, fry cannot employ this option when held in shallow rearing troughs and channels, thus they are more susceptible to the effects of gas supersaturation (Weitkamp 1976). Hatcheries combat supersaturation with various aeration devices such as: packed columns, baffled splash towers, agitators, spray nozzles and vacuum systems (SIGMA 1979; McLean and Boreham 1980 (a)).

The water supply at Puntledge Hatchery on Vancouver Island is often supersaturated in the spring (McLean and Boreham 1980 (b)). In May 1982, a die-off of summer chinook at Puntledge Hatchery, that eventually resulted in over 50% mortality, started about six weeks after the fish were transferred to the troughs. Significant losses of wild, pink and coho juveniles were also observed in the Puntledge River (H. Genoe pers. comm.). Laboratory examination of some of the mortalities suggested that gas supersaturation was the cause.

The following work was initiated in the spring of 1983 at the Puntledge Hatchery, to determine whether aeration of the water supply would improve juvenile chinook development and survival. Results presented compare growth, survival, incidence of disease and response to seawater between juveniles reared in aerated water and a control group of juveniles reared in unaerated water. Also, differences in water chemistry between treated (aerated) and control water supplies were compared.

SITE DESCRIPTION

This study was carried out at the Puntledge Hatchery's upper site from February to June 1983 (Fig. 1). The general arrangement of the upper site is shown in Fig. 2. The study used

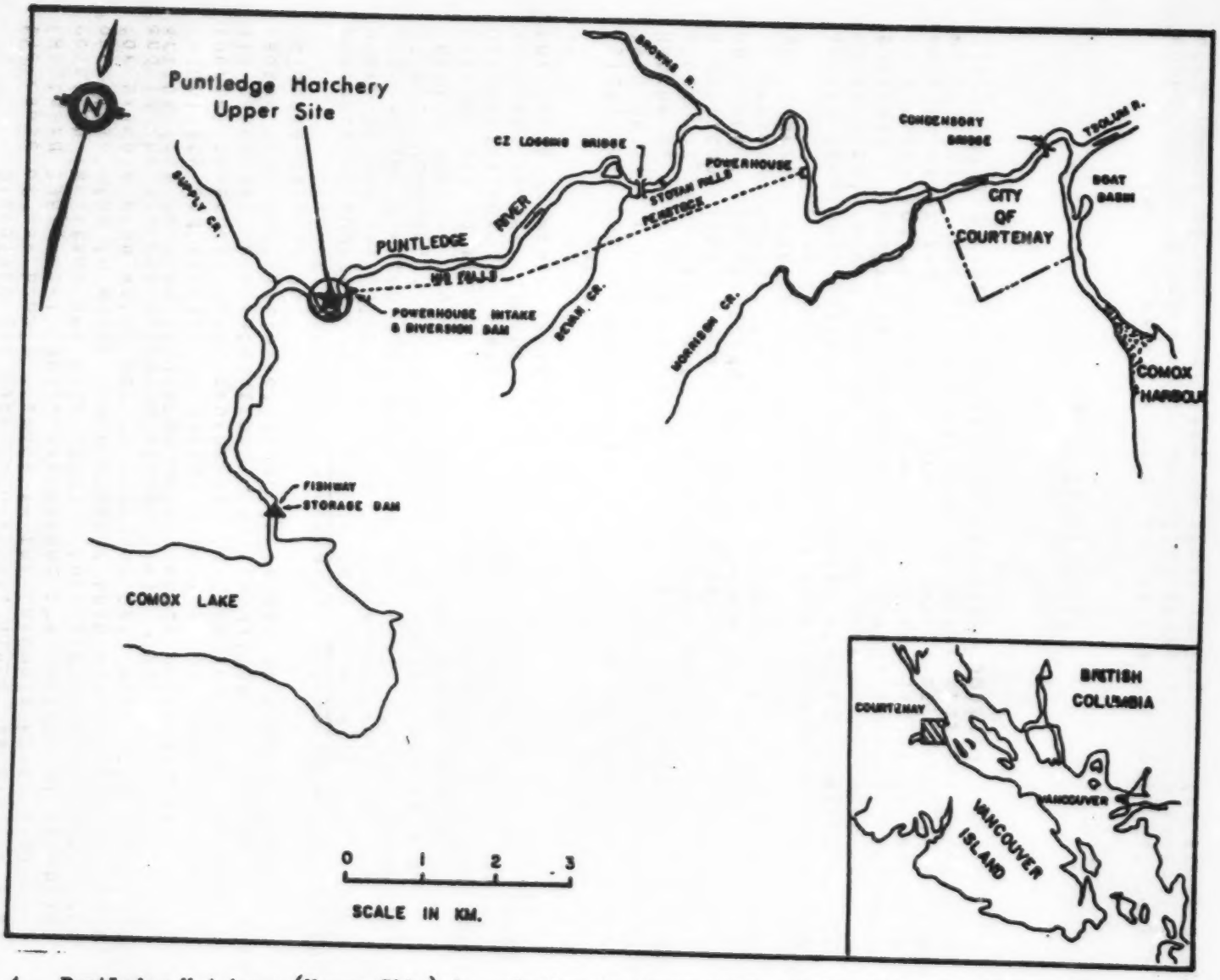

Fig. 1. Puntledge Hatchery (Upper Site) in relation to Comox Lake and the Hydro Station. Summer Chinook are reared at the Upper Site.

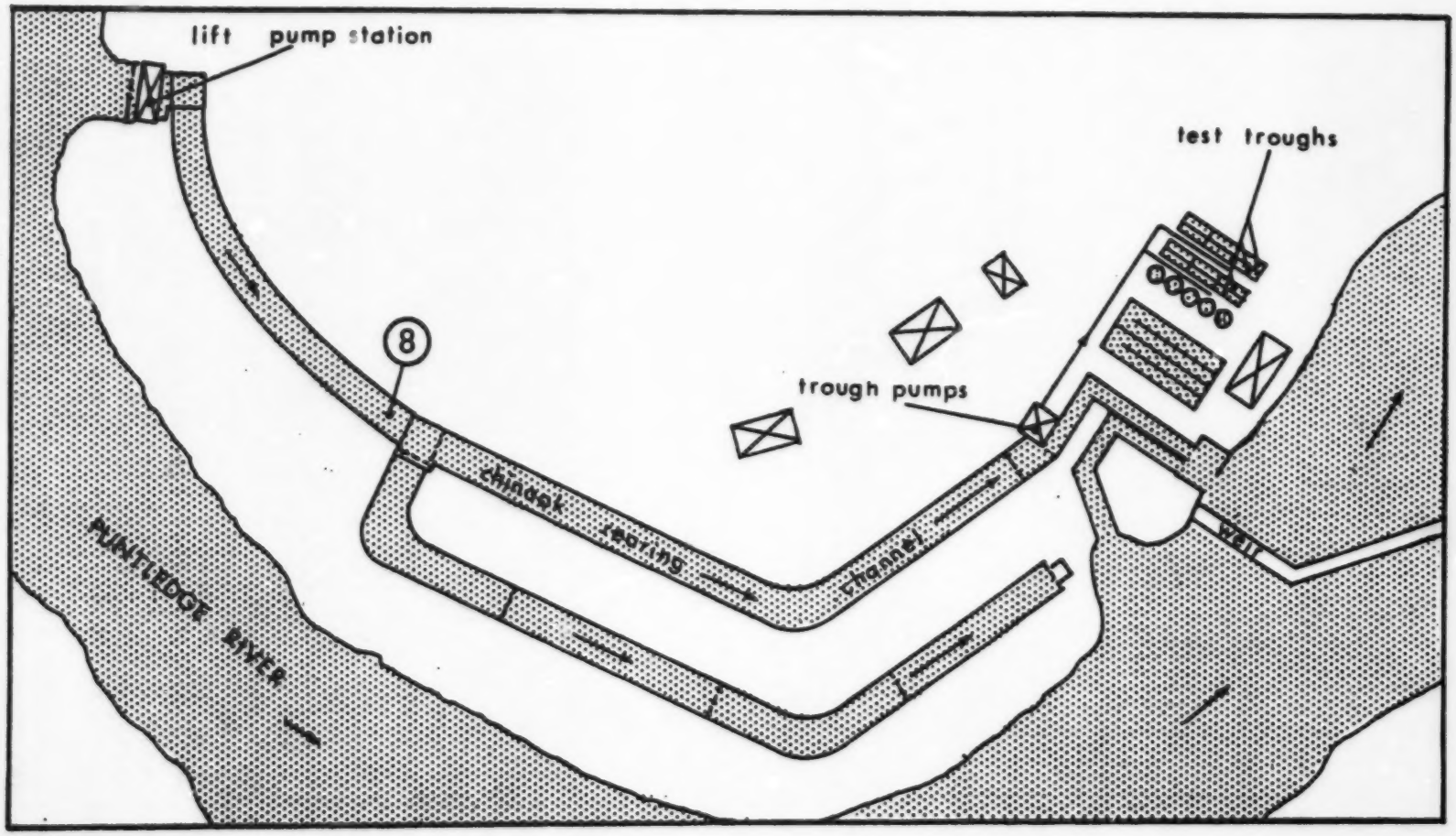

Fig. 2. Puntledge Hatchery Upper Site. General arrangement showing site 8 at the inlet to the production rearing channel. The 4 test troughs are also shown.

four (intermediate) rearing troughs and a rearing channel. Each trough was 6.1 m long, 0.813 m wide and had a water depth of 0.406 m. Troughs were constructed of fibreglass reinforced polyester resin. The rearing channel was 73.2 m long, 7.62 m wide and 1.37 m deep and was lined with gravel.

MATERIALS AND METHODS

Packed Column Aerators

The water supply for two of the troughs (No. 9 and 12) passed through packed column aerators (Fig. 3). The columns were 30.5 cm diameter segmented units; similar to those described by McLean and Boreham (1980 (a)). Aerator dimensions were:

Inside diameter: 30.8 cm
Number of segments: 7
Depth of packing per segment: 25 cm
Distance between segments: 15 cm
Height of opening between segments: 10 cm
Packing - "Flexirings": 38 mm (1 1/2 inch)

The water supply entered the non-aerated control troughs through a perforated splash plate.

Fish Culture Procedures

Four troughs were used in the experiment; two were control troughs and two had aerated water supplies. At ponding, each trough was stocked with 50,000 summer chinook fry which were randomly selected from a single egg take performed on October 11, 1982. At week seven of the study, the density of juveniles in the experimental troughs was reduced to 15,000 fish per trough. This density was maintained for the remainder of the rearing period. Between five and eight weeks after ponding, surplus fish from other intermediate troughs and ponds at Puntledge Hatchery were transferred to the rearing channel. Thus, by week eight, 1.3 million chinook fingerlings were rearing immediately upstream in the source water for the experimental troughs.

The fry were maintained and fed according to standard hatchery procedures. Daily records were kept of food size (Oregon Moist Pellet) and quantity (Appendix 2).

Daily mortalities for each trough were recorded by hatchery staff and dead fish were preserved in formalin for subsequent length measurement. Rearing channel mortalities were estimated from the numbers of dead fish found on the outlet screens.

Fish were crowded and subsampled by hatchery personnel for length and weight measurements as part of normal rearing

procedures. Juvenile condition coefficients, K, were calculated using the formula:

$$K = 100\ W/L^3$$

where: W = fish weight (mg)
L = fork length (mm).

Fry were sampled from each trough just after ponding in order to measure yolk reserve and the alevin developmental index, KD,

$$KD = 10\ W^{1/3}/L.$$

Fidell (1983) describes methods used for alevin analysis .

Water Quality Measurements

Weekly water quality measurements were made at each of the seven test locations, as shown in the flow schematic (Fig. 3) and occasionally at sample point 8 (Fig. 2). These parameters included: total excess gas tension (ΔP), dissolved oxygen, ammonia-nitrogen, pH, temperature, barometric pressure and flow rate.

Total ammonia-nitrogen levels were determined by the indophenol-blue spectrophotometric method (Zadorojny et al. 1973). A Bausch and Lomb "Spectronic 70" spectrophotometer was used to take light absorbance readings. pH levels were measured with a Fisher Accumet Model 292 digital pH meter. The meter was calibrated each day with standard buffer. Temperatures were taken with a calibrated mercury thermometer with 0.1° C graduations. Water flow rates through each trough were estimated from the average time required to fill a 20 liter container.

Water samples for metals analyses were taken monthly throughout the test period. Samples were preserved immediately with nitric acid and analyses were performed at the Dept. of Fisheries and Oceans, Water Chemistry Laboratory in West Vancouver.

Dissolved oxygen (DO) measurements were made using the Azide modification of the Winkler titrimetric method (APHA et al. 1975); 100 ml of the 300 ml samples were titrated with 0.01 N sodium thiosulphate. In order to reduce the loss of supersaturated gas, water samples were collected by siphon into 300 ml, pre-chilled, DO bottles and were immediately treated with manganese sulphate and alkaline-iodide-azide solutions.

Total excess gas tension (ΔP in mmHg) was measured using a Novatech Designs Ltd. tensionometer. This unit was zeroed in the atmosphere prior to each set of tests and was allowed to equilibrate for about 30 minutes in the sample before readings were taken. The probe was shaken regularly during this period.

At the time of each ΔP measurement, the barometric pressure was also measured using a calibrated aneroid barometer. Barographs over the entire study period were supplied by the Environment Canada Weather Station at Comox. This allowed continuous monitoring of changes in barometric pressure.

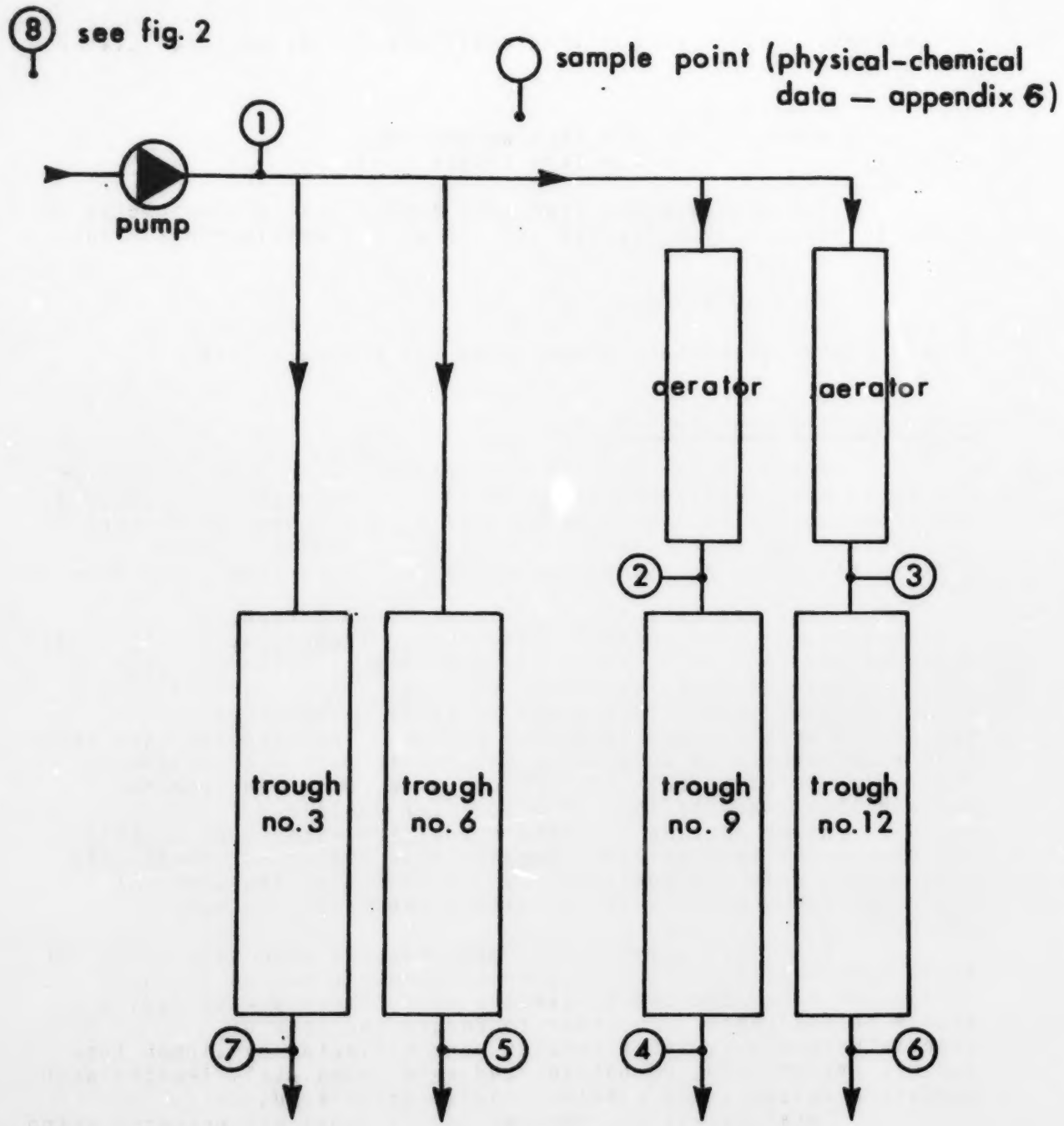

Fig. 3. Flow Schematic showing sample sites, control troughs (no. 3 and no. 6) and troughs with aerators (no. 9 and no. 12).

Continuous ΔP recordings were made at the inlets to the control troughs and the rearing channel (sites 1 and 8) in order to measure diurnal variations in the level of gas supersaturation. Recordings were taken during the month of May with a strip chart recorder connected to the tensionometer.

Gas Calculations

The uncompensated ΔP value (or ΔPu in mmHg) was calculated by subtracting the hydrostatic pressure available to the fish from ΔP using the following equation:

$$\Delta Pu = \Delta P - 73.6\ D$$

where: D = depth of rearing container (meters)

Total Gas Pressure (TGP), percentage oxygen and percentage nitrogen values were calculated using relationships described by McLean and Boreham (1980 (a)). These calculations were performed on an Apple microcomputer located at the Puntledge Hatchery. This program is fully described in the F.I.S.H. system documentation (Fishculture Information System for Hatcheries 1982). TGP was calculated from:

$$TGP\ (\%) = \frac{\Delta P + BP - WV}{BP - WV} \times 100\%$$

where: BP = barometric pressure (mmHg)
WV = water vapour pressure (mmHg)

The percent oxygen saturation was calculated from a model developed by Hitchman (1978). This model relates the oxygen saturation concentration to water temperature, barometric pressure and salinity. Values are almost identical with those predicted by Weiss (1970). The percent nitrogen saturation was calculated from the difference between the measured ΔP value and the partial pressure of the dissolved oxygen. The relationships necessary for this calculation were developed by Weiss (1970) and are described by Colt (1983). It should be noted that calculated nitrogen levels include a small amount of argon.

Free carbon dioxide concentrations were calculated from in situ pH and total alkalinity measurements. The total alkalinity value used for this calculation was the mean of 13 measurements taken during the spring over the last 5 years:

Mean = 17.1 mg/l as $CaCO_3$
Standard deviation = 0.79 mg/l

The method used to calculate free carbon dioxide is described in Standard Methods (1980). Because the alkalinity was not measured at the time the pH was measured, the reported carbon dioxide values are approximations. Briefly, this method uses the first ionization constant of aqueous carbon dioxide, K_1, to

predict the free CO_2 concentration in mg/l as a function of pH and alkalinity. The equations are:

$$CO_2 = 0.88\ A(10^{pK_1} - pH)$$

where: A = bicarbonate alkalinity (mg/l of $CaCO_3$; note that 17 mg/l was used in all calculations)

and $pK_1 = -\log K_1 = 6.5708 - 0.00988T$

where: T = temperature ^oC.

The relationship between K_1 and temperature was estimated from data presented in Stumm and Morgan (1970).

Disease Investigations

Examinations of moribund fish and random samples of 25 "healthy" fish per trough were made by the Diagnostic Service, Pacific Biological Station, Nanaimo on March 24, May 10 and June 17, 1983. A summary of examination procedures for healthy fish is given below (G. Hoskins pers. comm.):

- Aseptic streaking of kidney tissue onto Tryptic Soy Agar (TSA) for the detection of bacterial pathogens,
- Gross external and internal examination for signs of pathology,
- Microscopic examination of Giemsa stained blood smears for detection of changes in erythrocyte size or morphology,
- Microscopic examination of Gram stained kidney tissue smears for detection of viral, parasitic and bacterial disease organisms,
- Hematocrit determination (May 10 and June 17 samples only),
- Histological evaluation of gill structures and internal organs in H&E sections.

The numbers of moribund fish examined per trough were:

Date	Number Examined			
	Trough 3	Trough 6	Trough 9	Trough 12
March 24	12	10	10	10
May 10	0	0	0	0
June 17	6	4	2	0

Because of post-mortem changes (autolysis etc.), work was limited to a gross examination and streaking of kidney tissue onto TSA.

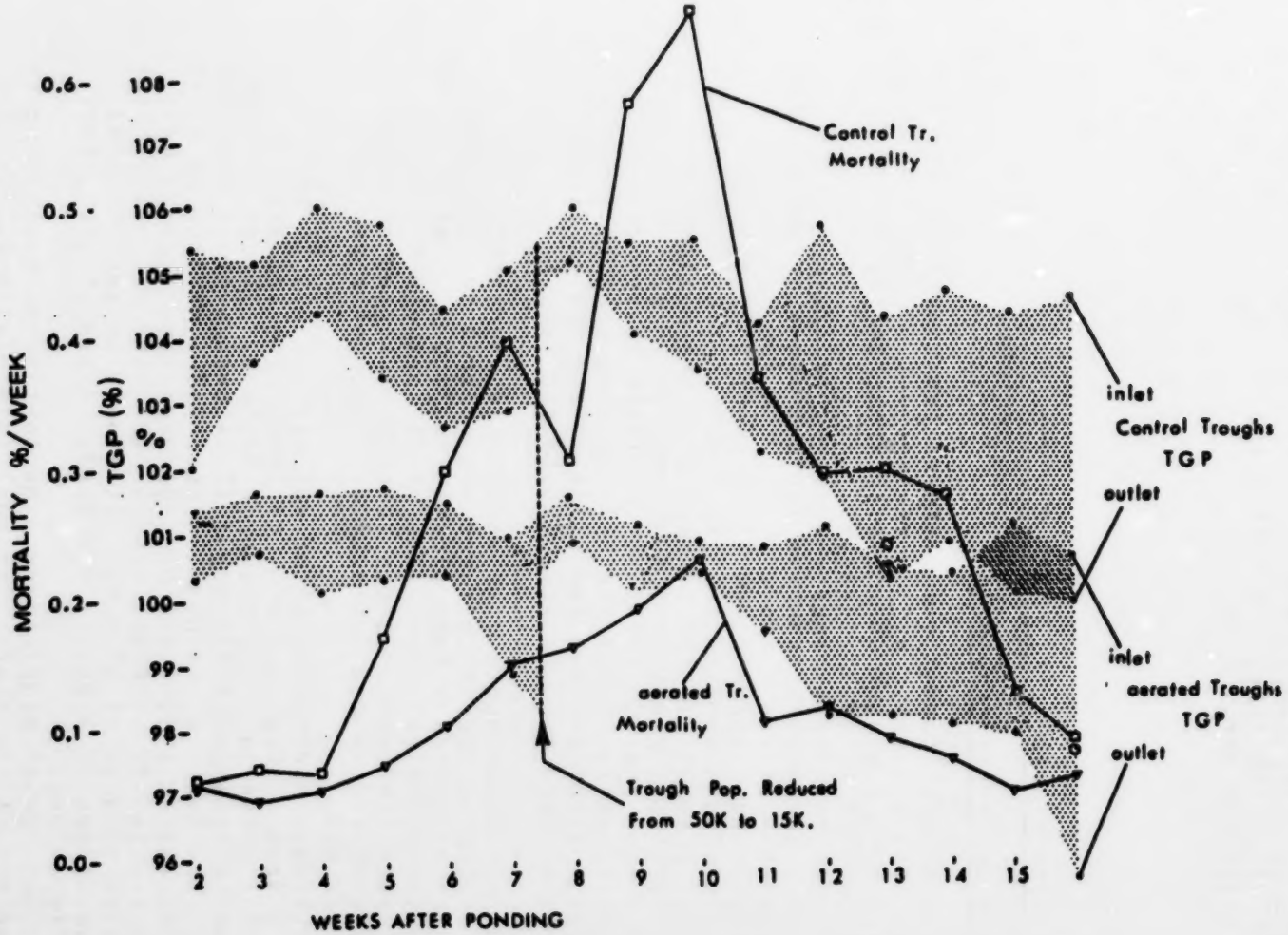

Fig. 4. Average weekly mortality rates (% per week) for the control and aerated troughs vs. time (weeks after ponding). TGP at the inlet and outlet of the experimental treatments (averaged over replicate troughs) has also been plotted against time. The stippled area shows the range of TGP within each treatment.

Seawater Challenge

Live samples of approximately 20 fish per trough, were taken to the Pacific Biological Station for measurement of seawater tolerance. The level of plasma sodium after a 24 hour exposure to seawater indicates how well a smolt can tolerate seawater (J. Blackburn pers. comm.).

RESULTS

Environmental Conditions

Total Gas Pressure and ΔP

Environmental conditions differed substantially between control and aerated troughs. Weekly measurements for various parameters have been averaged over the 16 week rearing period to show the magnitude of these differences (Table 1). Because conditions between replicate troughs were generally very close (see Appendix 6), parameters shown in Table 1 are averages of the values for each pair of replicates.

Table 2 shows the maximum differences that existed between the control and aerated troughs for specific environmental parameters. For example, it can be seen that the maximum difference in Total Gas Pressure (TGP) occurred in week 8 of the study. At this time the TGP level at the inlet to the control troughs was 106.0% while TGP at the inlet to the aerated troughs was only 101.5%. Also, the average of inlet and outlet levels in the control and aerated troughs were 105.6% and 101.2% respectively.

Figure 4 superimposes the weekly measurements of TGP on the mortality patterns for the aerated and control troughs. Both inlet and outlet values have been plotted in Fig. 4. The stippled area on the graph represents the range of TGP between the inlet and outlet of each treatment. (Measurements presented in Appendix 6 and displayed in Fig. 4 and Table 1 were taken once per week between 1000 and 1200).

Continuous monitoring of ΔP was carried out at site 1 (Fig. 3) for 8 days in May; minimum, maximum, noon and average daily values for these days are shown in Table 3. It can be seen that measurements taken near mid day fell between average and peak daily values. For example, on May 17 there was a maximum ΔP of 39 mmHg (TGP = 103.9%) at 1530 and a minimun measurement of 21 mmHg at 0600. The average for the day was 29 mmHg, and the measurement at 1200 resulted in a ΔP of 30 mmHg. It should be kept in mind that the values shown in Appendix 6 and Fig. 4 are slightly less than peak daily values.

Several "grab" samples and some continuous monitoring of ΔP was carried out at the rearing channel inlet (site 8, Fig. 2). Typical 24 hour ΔP recordings are shown in Fig. 5. A summary of all measured ΔP values (both grab and continuous) is presented for the rearing channel in Table 4. Where there were continuous

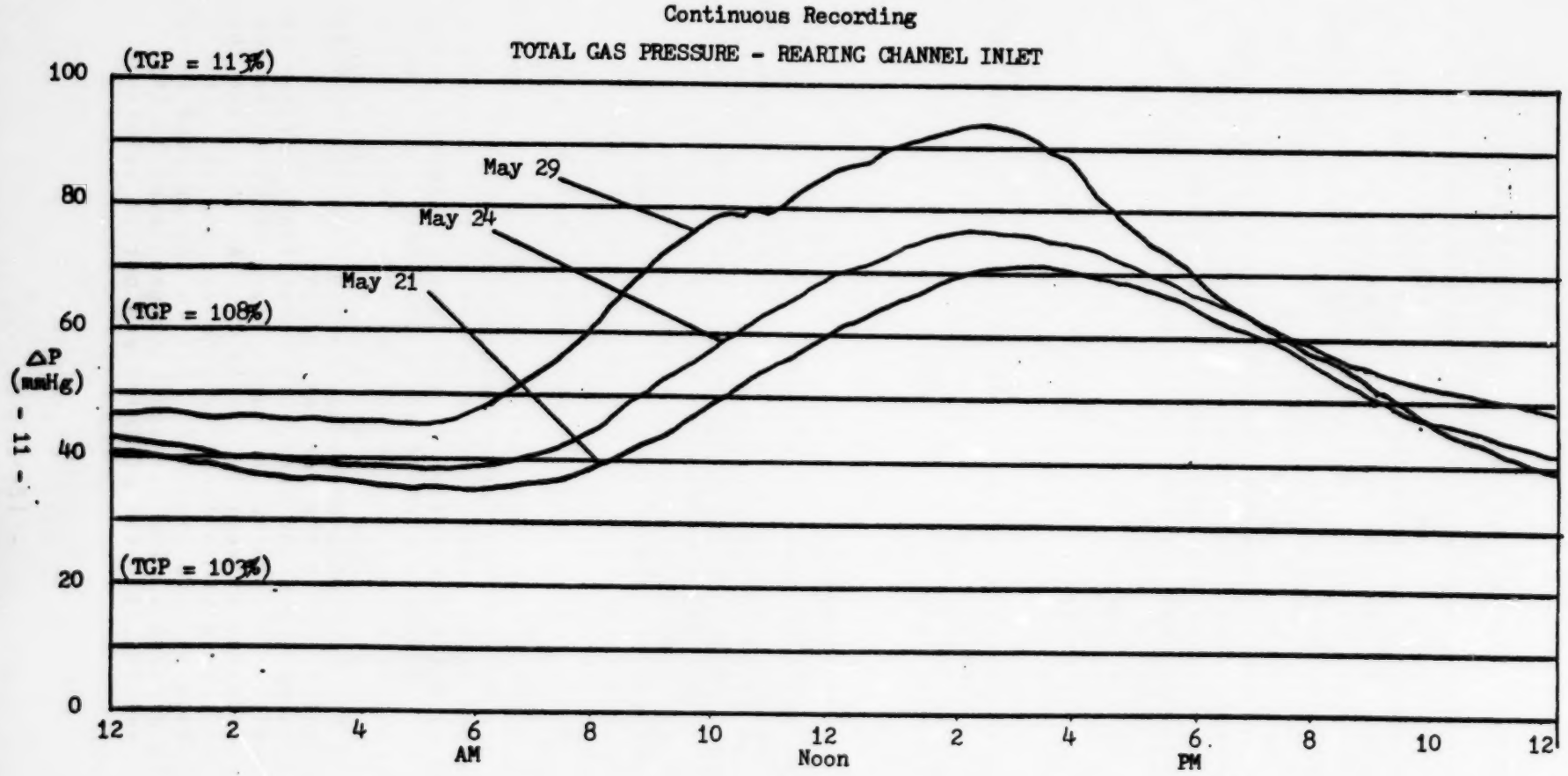

Fig. 5. Some typical examples of the daily variation in "ΔP" at the inlet to the production rearing channel (site 8). Approximate TGP values are also shown on the "y" axis - these values were calculated by assuming a barometric pressure of 750 mmHg.

records, the minimum, maximum and average daily ΔP values have been shown.

The "uncompensated ΔP" (ΔPu) values are shown for the rearing troughs in Tables 1 and 2. Briefly, the calculation involves subtracting the pressure due to water depth from the measured ΔP value. If the fish were at this water depth, uncompensated ΔP gives an approximation of the pressure available for bubble growth in the fish. The results shown in Tables 1 and 2 have used the maximum water depth available to the fish for prediction of the uncompensated ΔP.

Only the control troughs had a ΔPu value which was consistently greater than zero. On average, the control trough inlets had a ΔPu value of 7 mmHg (approx. TGP of 101%) (Table 1). At the trough outlets however, the ΔPu had generally dropped to less than 0 mmHg although during week 8 ΔPu was greater than zero throughout the entire trough (Table 2). ΔPu in the aerated troughs however, remained below zero even during week 8.

The uncompensated ΔP values in the rearing channel were always less than zero, in spite of the high measured excess gas tension values (peak ΔP = 93 mmHg, TGP = 112%) (Table 4). This was due to the 1.4 meters of water available to the fish in the rearing channel. With this water depth, the measured ΔP would have to be above 103 mmHg (TGP = 113.7%) to give an uncompensated ΔP value greater than zero.

Oxygen and Nitrogen

Oxygen and nitrogen were the main components of total gas pressure (Tables 1 and 2). On average, the dissolved oxygen concentration was lower in the control troughs than in the aerated troughs. Nitrogen levels on the other hand, were highest in the control troughs. This was expected as the outflow from the rearing channel was used as the inflow to the experimental troughs. The aerators tended to bring all gas components to equilibrium. In the later weeks of the study, they tended to increase the oxygen concentration and decrease the nitrogen concentration. Hence, the aerated troughs were presented with near ideal water quality.

Table 2 shows that even during week 14, when the maximum differences in oxygen occurred between control and aerated troughs, the oxygen level at the inflow to the aerated troughs was 97.6% (10.23 mg/l) while the inflow to the control troughs was 86.2% (9.08 mg/l). However, over 16 weeks of monitoring, the average oxygen concentrations in the aerated and control troughs were remarkably similar. Table 1 shows that the average oxygen concentration in the control troughs was only 0.03 mg/l lower than the average concentration in the aerated troughs.

Nitrogen on the other hand, was consistently higher in the control troughs. The maximum nitrogen level measured in the control troughs occurred at week 12 (Table 2). At this time the nitrogen level at the inlet to these troughs was 108.5%. It should be noted that at this time the inlet to the aerated troughs was only 102% in nitrogen. The average nitrogen level in the control troughs was 106.6% (mean of inlet and outlet values in

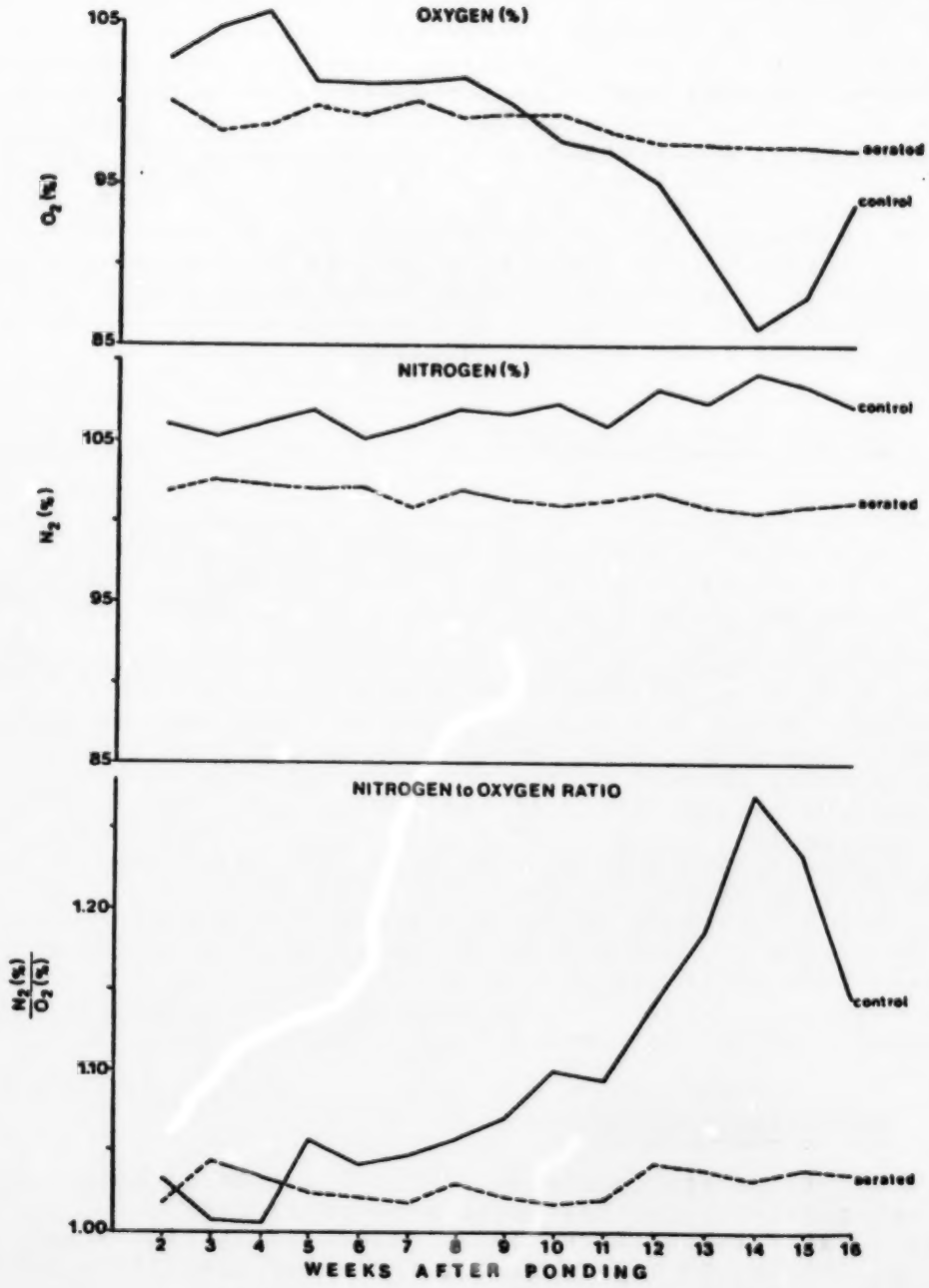

Fig. 6. Oxygen (%), nitrogen (%) and nitrogen to oxygen ratios for aerated and control troughs over the study period.

Table 1) while the mean level in the aerated troughs was 102%. Oxygen and nitrogen saturation levels and nitrogen to oxygen ratios have been taken from Appendix 6 and plotted against time in Fig. 6.

Oxygen and nitrogen levels were not measured consistently at the production rearing channel. However, values could be inferred from the ΔP measurements taken at the channel inflow (site 8); results are summarized in Table 4. Since minimal fish rearing takes place upstream of the rearing channel and since gas supersaturation at the Puntledge Hatchery is caused mainly by solar heating, it is reasonable to assume that the levels of saturation in nitrogen and oxygen are the same at the inflow to the rearing channel. For example, on May 29 the ΔP value of 93 mmHg resulted in a TGP value of 112%, which was assumed to be 112% in nitrogen and 112% in oxygen. This assumption was supported by a few grab samples taken during the study.

pH and Carbon Dioxide

pH measurements varied from 7.67 to 6.81 (Appendix 6). The highest levels generally occurred at the aerated trough inlets and the lowest levels occurred at the control trough outlets. pH was lowered by passage through the rearing channel and was lowered further by passage through the troughs. The aerators generally raised the pH by 0.15 to 0.40 units.

Carbon dioxide was not measured directly. Values shown in Table 2 were calculated from pH, alkalinity and temperature measurements. Almost all the pH variations observed can be explained in terms of either carbon dioxide addition by the fish or carbon dioxide removal by the aerators. The aerators removed CO_2 and thereby raised the pH of the inflow water to trough 9 and 12. The inflow to troughs 3 and 6, on the other hand, had slightly higher carbon dioxide concentrations and therefore slightly lower pH levels.

The greatest pH difference between treatments occurred at week 14 (Table 2). At this time the average pH in the control troughs was 6.92 while the average pH in the aerated troughs was slightly higher at 7.14. This corresponded to free carbon dioxide concentrations of 5.2 mg/l and 3.7 mg/l respectively.

Water Temperature

The temperatures shown in Fig. 7 are those observed on the days when water chemistry tests were performed. The maximum water temperature values displayed in Fig. 7 were measured at the trough inlets during the water sampling program. Daily minimum temperatures on the other hand were taken from the hatchery thermograph located near sample site 1 (Appendix 7). The temperatures shown in Appendix 6 are those recorded at the time of the TGP measurement and oxygen sampling. The temperatures rose from approximately 5° C to 14° C during the 16 week period.

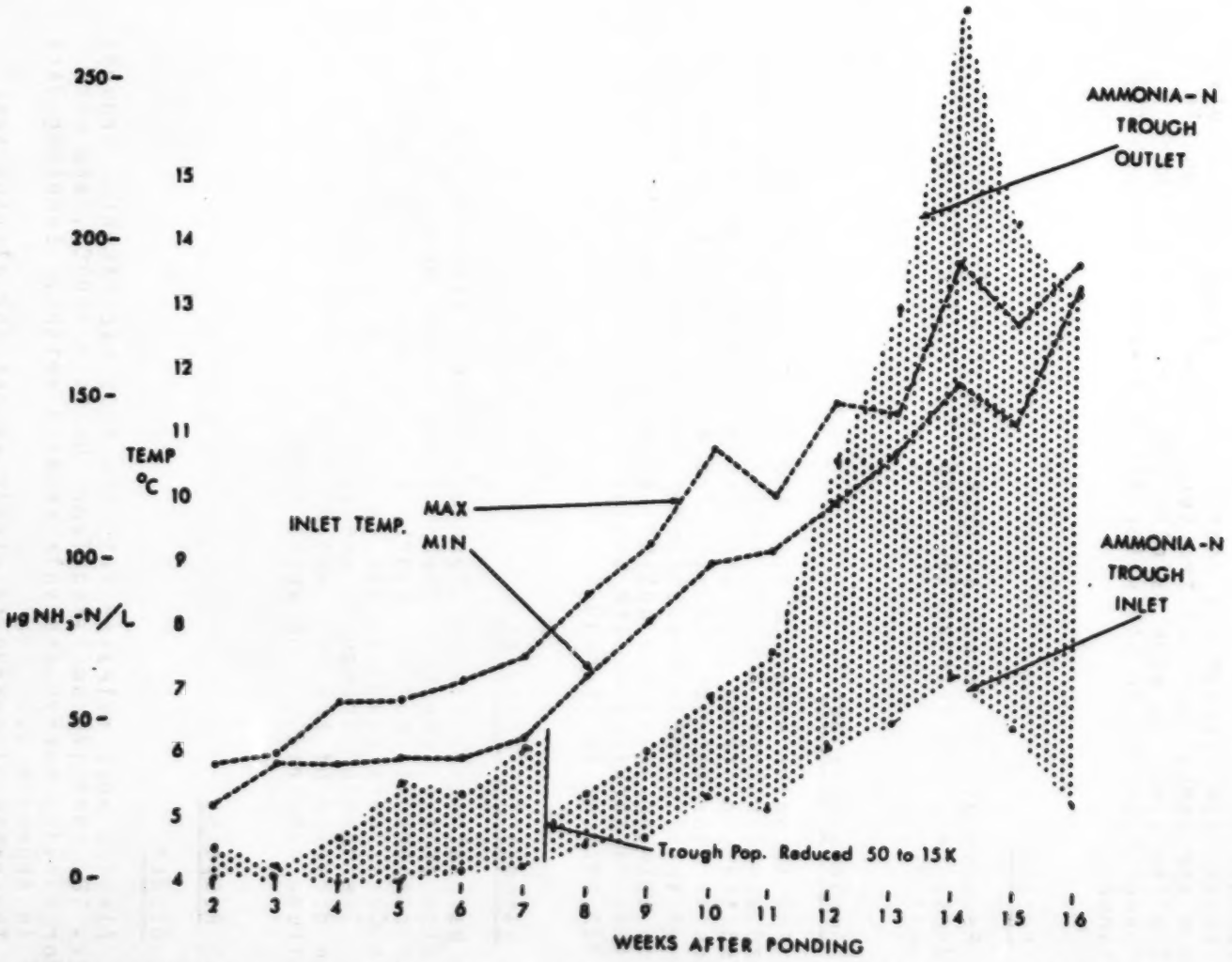

Fig. 7. Inlet and Outlet temperature values and total ammonia - N concentrations (ug/L) vs time. Values have been obtained by averaging over both experimental treatments.

Water Flows

Water flow rates through each trough varied somewhat, but generally remained between 200 and 300 L/min during the test period (Appendix 6).

Water flow through the rearing channel was approximately 34,000 L/min throughout most of the test. Flows rose to double this level after week 14, when maintenance work on the other rearing channel resulted in all water being diverted through the chinook channel.

Metals

Results of the metals analyses are shown in Appendix 8. Total hardness remained between 15.7 and 16.9 mg/l as $CaCO_3$ during the test period.

Ammonia-Nitrogen

The incoming water to both the control and aerated troughs had similar total ammonia levels (Appendix 6). The trough outlet conditions differed from each other slightly due to minor differences in flow rates. The stippled area (Fig. 7) represents the range of total ammonia present over the length of the troughs (difference between inlet and outlet values). The maximum level of total ammonia occurred at the outlet to aerated trough 12 in week 14 (315 ug/l at pH of 6.90).

Barometric Pressures

Barometric pressures (Appendix 6) were taken at the hatchery site at the same time that TGP and oxygen were measured. Continuous barographs from the nearby Environment Canada Weather Station at Comox were examined for major drops in atmospheric pressure. The maximum change in pressure in any 24 hour period during the duration of the test was 10 mmHg — pressure changes of this magnitude occurred during weeks 4 and 7.

Biological Response

Growth

Alevins were released into the four experimental troughs on February 18, 1983 (Accumulated Temp. Units = 910°C), and were sampled for alevin, embryo and yolk reserve weight. Sampling data are shown in Appendix 1.

The ratio of embryo to alevin weight for alevins sampled from the control troughs averaged 90.5% (79.6% on a dry weight basis) while the sample from the aerated troughs averaged 89.2% (78.5% on a dry weight basis). There was no significant

difference in initial yolk reserves between the treatment and control alevins.

Daily food rations and growth data for juveniles from the experimental troughs and rearing channel are summarized in Appendix 2. At release, after 122 days of rearing, the treatment and control alevins were almost identical in weight — control samples averaged 8.56 grams while samples from the aerated troughs averaged 8.92 grams (Appendix 2). The relative variation in fish weights within the troughs was also similar. The mean coefficient of variation (SD / mean x 100%) at release was 22.0% for the control troughs and 20.9% for the aerated troughs.

Seawater Challenge

At smolt release (June 20/83) samples of 20 fish each were taken from Trough 6 (control), Trough 12 (aerated) and the production rearing channel. Table 6 presents their plasma sodium levels after exposure to seawater.

The 95% confidence intervals for the mean plasma sodium levels were:

Control (Trough 6) = 166.4 to 171.8
Aerated (Trough 12) = 159.7 to 165.5
Rearing Channel = 162.6 to 166.8

Plasma sodium levels differed significantly between smolts from the control and aerated troughs ($P<0.05$).

Disease Investigations

Appendix 3 presents detailed results from the disease examinations. No infectious diseases were found in fish sampled on March 24 and May 10. However, furunculosis was detected in 7 out of 12 moribund fish sampled from control troughs 3 and 6 and aerated trough 9 on June 17. This pathogen was not detected in random samples of healthy fish from these troughs.

The March 24 samples of healthy fish from the control troughs showed a slight degree of liver vacuolation. This condition seemed to diminish over the rearing period. Also, fish from the control troughs had a slightly higher hematocrit level than fish from the aerated troughs (43% for control vs 41% for aerated samples).

It should be emphasized that gross external and internal examinations did not reveal any of the symptoms normally associated with gas bubble disease.

Mortality

Total mortality in the control troughs was 2.65 times higher than total mortality in the aerated troughs; however the level of total mortality remained low in both groups (4.1% for control vs 1.6% for aerated troughs).

Weekly mortality data are presented in Appendix 4. As there was very close agreement in mortality rates for replicate troughs, they were averaged (Fig. 4).

Mortality rates were very low during the first four weeks of rearing. In the second week for example, the control group mortality averaged 0.059% while the aerated trough mortality averaged 0.058%. Mortalities started to rise in all troughs about four weeks after ponding, reaching a maximum from weeks 9 to 11. During week 10 the control and aerated trough mortality rates peaked at 0.652% and 0.231% respectively. After this peak, mortality gradually decreased in all troughs. At week 16, just prior to release, the mortality rate was 0.097% for the control troughs and 0.061% for the aerated troughs.

Rearing channel mortalities followed a similar pattern to that of the experimental troughs, rising to 0.506% in week 11 and then decreasing gradually to 0.081% by week 16. Mortality due to transfers of fish or other handling stresses was not included in these results.

From week 10 until the end of the test period mortalities were subsampled, preserved in formalin and measured for fork length. This was done by collecting weekly, all the dead that occurred in the four troughs over a one day period. Length measurements for mortalities and healthy fish are tabled in Appendix 5. Of the 102 mortalities measured for length, 90 were less than two standard deviations below the mean length of the healthy fish.

DISCUSSION

The 1983 chinook rearing program at the Puntledge Hatchery was characterized by good growth of juveniles and unusually high fry to smolt survivals. The lack of high mortalities, as occurred in April of 1982, makes assessment of the benefits of aeration at this site very difficult. It is not clear, whether installation of aerators would significantly alleviate the type of rearing problems that have occurred at this site in the past. However, the data collected does provide insight into the effects of chronic exposure to low level gas supersaturation.

Total Gas Pressure, ΔP and % nitrogen were the only parameters which differed significantly between the control and aerated troughs over the study period (Table 1). Thus it is reasonable to relate differences in biological response to differences in TGP and nitrogen levels.

Although the aerators influenced pH, CO_2 and oxygen, the differences in these parameters between treatment and control troughs were minor (Tables 1 and 2). The only values which were consistently outside the water quality criteria (SIGMA 1983) for salmonid rearing, were nitrogen and TGP levels measured at the control troughs.

This point is further emphasized by examining environmental conditions at week 10, the period of highest mortality (Fig. 4). At this time the average oxygen concentrations and percent saturation in the control and aerated troughs were 10.69 mg/l (95.7%) and 10.85 mg/l (96.7%) respectively. The average carbon dioxide concentrations in the control and aerated troughs were 2.1 mg/l and 1.3 mg/l respectively while the average pH levels were 7.34 and 7.56. The average un-ionized ammonia-N concentration was very low in both treatments (0.2 ug/l for the control vs 0.3 ug/l for the aerated troughs). These results represent excellent environmental conditions (SIGMA 1983) and should not produce detrimental effects in either treatment or control troughs. However, the average nitrogen level in the control troughs (nitrogen = 106.9%, TGP = 104.5%) was significantly higher than the nitrogen level in the aerated troughs (nitrogen = 101.7%, TGP = 100.7%). During week 10 the mortality in the control troughs was 2.8 times the mortality in the aerated troughs. This suggests that differences in mortality were related to the level of nitrogen supersaturation.

Both treatments showed similar trends in mortality over the rearing period (Fig. 4). However, as noted earlier the aerated troughs experienced a significantly lower mortality than the control troughs.

Table 5 relates total mortality to water quality conditions believed to be associated with this response. Because gas supersaturation levels vary with time and between the trough's inlet and outlet, describing the supersaturation level for a particular treatment is difficult. Hence, Table 5 includes both average and peak values experienced over the study period.

As explained previously, the uncompensated ΔP value (ΔPu) shows the gas pressure available for bubble growth if the fish were at the maximum water depth. This is a calculated value. It should be emphasized that the actual uncompensated ΔP value would vary continuously as the fish moved through the water column. Knittel et al. (1980) showed that differences in response times to ΔP at various depths are explained by using ΔPu. This reinforces the view that ΔPu is a more biologically meaningful expression of supersaturation than ΔP or TGP(%).

This hypothesis is consistent with the Puntledge Hatchery results. The production channel experienced by far the highest ΔP or TGP values (Table 4). However, due to the 1.4 meter water depth, the ΔPu value remained less than zero over the entire rearing period. In the aerated troughs ΔPu also remained less than zero (Table 5). On the other hand, the ΔPu values for the control troughs were greater than zero for much of the time (Table 5). Rearing containers where ΔPu remained less than zero showed a significantly lower mortality rate than the control troughs (peak ΔPu was 15 mmHg).

Total uncompensated gas tension (ΔPu) is an important factor influencing the biological response of juvenile salmon to supersaturation. However, it is generally accepted that the response is more severe at high nitrogen to oxygen ratios (Rucker, 1976). In other words, a given ΔPu level is more detrimental if it is caused by nitrogen rather than oxygen supersaturation.

Both the production rearing channel and the aerated troughs had nitrogen (%) to oxygen (%) ratios near 1.0 whereas the control troughs experienced ratios greater than 1.05 over most of the rearing period (Fig. 6). Thus, the control troughs had both the highest ΔPu values and the highest nitrogen to oxygen ratios. It is proposed that the differences in these parameters were responsible for differences in the mortality rates between control and aerated troughs, and at least partially responsible for differences in mortality observed between the production rearing channel and the control troughs.

Besides higher rates of mortality, control trough fish also had the highest blood sodium levels after exposure to seawater (169.1 meg/l for control vs 162.6 meg/l for the aerated troughs). This suggests that smolts from the aerated troughs could adapt to seawater more effectively than could smolts from the control troughs. Unfortunately the seawater challenge test was only carried out on one replicate from each treatment (samples were taken from Troughs 6 and 12). Although the differences in blood sodium levels between Troughs 6 and 12 were statistically significant, both replicate troughs should have been sampled to verify the differences between the experimental treatments.

The average weight of the smolts from the control troughs was slightly less than the average weight of smolts from the aerated troughs (8.56 g vs 8.92 g). This difference was not statistically significant. However, the differences in the condition coefficient, K, were significant at the 0.05 level. The mean values and their 95% confidence intervals for pooled samples from the control and aerated troughs were 1.110 $\pm$ 0.0139 and 1.135 $\pm$ 0.0098 respectively. Thus fish from the aerated troughs were slightly heavier, relative to their length, than fish from the control troughs.

A subtle difference in behavior was also noted between the experimental and control groups. Fish in the control troughs tended to hold nearer to the inlet. The feeder placement, trough dimensions and water flow were identical for both sets of troughs. Thus there was no obvious physical reason that would account for this difference in behavior.

Gross external and internal examinations for disease did not reveal any of the symptoms commonly associated with gas bubble disease. However, histological examination of the liver revealed conditions that might have been related to gas supersaturation. Samples of healthy fish from the control troughs all had a slight degree of liver vacuolation. This condition is thought to be similar to liver damage observed by Pauley and Nakatani (1967) in chinook salmon fingerlings having gas bubble disease (G. Hoskins pers. comm.).

Although the biological effects discussed so far were statistically significant, their implications to large scale fish culture are not clear. All the differences observed between the aerated and non-aerated troughs were subtle and probably of little relevance to large scale fish culture. For example, the highest total mortality in a control trough over 122 days of rearing was only 4.4% (control Trough 3, Appendix 4). This represents a very low mortality rate for a production rearing operation. It should

also be kept in mind that most of the juvenile mortalities were extremely small fish (Appendix 5).

This work set out to assess the benefits of installing aerators on the water supply used for rearing summer chinook salmon at the Puntledge Hatchery. The cost of aeration could be justified if high mortality rates could be reduced by aeration. The 1983 experiments did not adequately address this question since fish health problems in the non-aerated troughs were insignificant. Nevertheless the results do demonstrate a subtle but definite response to low levels of supersaturation. Therefore it is recommended that the experiment be repeated. Further experimentation should give a clearer assessment of the benefits of aeration, and should also provide a better understanding of the biological effects of supersaturation.

There are a number of contradictory interpretations of the 1983 results:

(1) It could be argued that supersaturation levels and patterns experienced this year were typical of previous years. Since these levels were incapable of causing a significant juvenile mortality, it could be concluded that previous fish health problems were unrelated to gas supersaturation. Under this hypothesis installation of aerators would provide only a minor benefit.

(2) It could be argued that these results show that supersaturation acts as a stressor. This is indicated by the fact that juveniles reared in non-aerated troughs had higher mortality, higher blood sodium levels after seawater exposure, lower K values and showed subtle behavioral differences. Thus supersaturation, in the presence of a pathogen, might precipitate serious fish health problems. Under this hypothesis, aerators would alleviate stress and thus reduce mortality.

(3) It may be that levels of supersaturation experienced this year were simply not severe enough to cause problems. Since supersaturation is caused by solar heating and by spillage from the storage dam at the outlet of Comox Lake, levels encountered would be expected to vary from year to year. Other environmental factors which greatly influence the response to supersaturation might also vary annually. These include: barometric pressure, water hardness, temperature and the nitrogen to oxygen ratio. Detrimental fluctuations in one or more of these factors, even in the absence of a pathogen, may cause severe fish health problems. Under this hypothesis, aeration would provide a significant degree of protection.

These scenarios are reasonable and consistent with the 1983 results. Each one has important implications for the rearing of chinook salmon at the Puntledge Hatchery. Continuation of this program would not only benefit this particular chinook rearing

operation, but would also improve our understanding of the response of salmonids to gas supersaturation.

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Table 1. Environmental conditions for inlet and outlet water in the control and aerated troughs have been averaged over the study period.

Average Environmental Conditions over Study Period	Control Troughs Mean	Control Troughs Standard Deviation	Aerated Troughs Mean	Aerated Troughs Standard Deviation
TGP (%)				
- inlet	105.1	0.6	101.1	0.5
- outlet	102.4	1.7	99.2	1.6
ΔP (mmHg)				
- inlet	37	5	8	4
- outlet	18	13	- 6	12
N_2 as % of Saturation				
- inlet	107.0	1.2	101.8	0.6
- outlet	106.1	1.2	102.2	1.2
O_2 as % of Saturation				
- inlet	97.9	5.9	98.7	1.14
- outlet	88.7	9.4	88.3	8.30
O_2 concentration (mg/l)				
- inlet	11.26	1.32	11.33	0.80
- outlet	10.12	1.59	10.11	1.44
pH				
- inlet	7.22	0.11	7.42	0.11
- outlet	7.08	0.14	7.17	0.17
Uncompensated ΔP at depth of rearing container (mmHg)				
- inlet	7	5.0	< 0	
- outlet	< 0		< 0	
Water Flow (l/min)	240	62	251	63

* Average values have been derived from Appendix 6.

Table 2. Maximum differences in environmental conditions between the control and aerated troughs. These occurred at different times depending on the environmental factor being considered.

Environmental Factor	Week No.	Control Troughs	Aerated Troughs
TGP %	8		
- inlet		106.0	101.5
- outlet		105.2	100.8
- average		105.6	101.2
ΔP (mmHg)	8		
- inlet		45	11
- outlet		39	6
- average		42	9
N_2 as % of Saturation	12		
- inlet		108.5	102.0
- outlet		106.7	102.1
- average		107.5	102.1
O_2 as % of Saturation	14		
- inlet		86.2	97.6
- outlet		66.1	70.3
- average		76.2	84.0
O_2 concentration (mg/l)	14		
- inlet		9.08	10.23
- outlet		6.82	7.32
- average		7.95	8.78
pH	14		
- inlet		6.99	7.40
- outlet		6.84	6.87
- average		6.92	7.14
Uncompensated ΔP at depth of rearing container (mmHg)	8		
- inlet		15	< 0
- outlet		9	< 0
- average		12	< 0
Water Flow (l/min)	14	239	198
Calculated Free Carbon Dioxide (mg/l)	14		
- inlet		4.3	1.7
- outlet		6.0	5.6
- average		5.2	3.7

* Maximum values have been derived from Appendix 6.

Table 3. Continuous monitoring of ΔP was carried out at the inflow to the control troughs (site 1 in Fig. 3) over a portion of the study period.

Date	Minimum ΔP(mmHg)	Time	Maximum ΔP(mmHg)	Time	Noon Value ΔP(mmHg)	Average Daily Value ΔP(mmHg)	SD
May 10	-	-	51	1600	39	-	-
May 11	21	0630	52	1530	40	34	10.7
May 12	19	0600	49	1530	39	31	10.8
May 14	20	0600	33	1700	27	26	3.8
May 15	18	0600	46	1530	36	31	10.1
May 16	23	0600	40	1730	32	30	5.8
May 17	21	0600	39	1530	30	29	5.7
May 18	20	0600	46	1330	44	33	9.3

Table 4. Characterization of gas levels at the inflow to the rearing channel (site 8). ΔP (mmHg) values were measured either on a continuous or grab sample basis. Grab samples were taken between 1200 and 1500. On days where continuous monitoring was carried out, minimum, maximum and average daily values have been shown (SD = standard deviation). Approximate TGP levels could be calculated if a barometric pressure of 750 mmHg is assumed.

		Continuous Monitor ΔP					
	Grab Sample	Minimum		Maximum		Average	Daily
Date	ΔP	ΔP	Time	ΔP	Time	Value ΔP	SD
Feb 28	40	-	-	-	-	-	-
Mar 11	42	-	-	-	-	-	-
Mar 18	55	-	-	-	-	-	-
Mar 25	47	-	-	-	-	-	-
April 8	47	-	-	-	-	-	-
April 15	58	-	-	-	-	-	-
April 22	51	-	-	-	-	-	-
April 29	69	-	-	-	-	-	-
May 6	40	-	-	-	-	-	-
May 13	49	-	-	-	-	-	-
May 20	41	-	-	-	-	-	-
May 21	-	35	0600	71	1500	51	12.8
May 22	-	37	0600	74	1530	52	13.2
May 23	-	37	0530	76	1500	53	13.9
May 24	-	38	0530	77	1430	56	13.6
May 25	-	42	0530	74	1345	55	10.1
May 26	-	44	0530	76	1430	57	11.5
May 27	-	40	0500	75	1600		
May 28	-	42	0530	86	1330	61	15.7
May 29	-	45	0500	93	1430	63	18.1
May 30	-	38	0500	80	1515	54	13.8
May 31	-	40	0500	72	1000	53	13.5
June 1	-	-	-	76	1300	-	-
June 2	-	42	0530	74	1630	55	11.3

Table 5. Total mortality over the 122-day rearing period for the control and aerated troughs have been shown along with the environmental conditions believed to be associated with the response.

Treatment	Average of 16 grab samples taken over study period. TGP%	N_2 %	ΔPu	Peak values measured over study period. TGP%	N_2 %	ΔPu	Total mortality over 122 days of rearing.
Control							
- inlet	105.1	107.0	7	106.0	108.5	15	Trough 3 = 4.4%
- outlet	102.4	106.1	<0	105.2	106.7	9	Trough 6 = 3.7%
- mean	103.8	106.6		105.6	107.6	12	Mean = 4.1%
Aerated							
- inlet	101.1	101.8	<0	101.5	102.0	<0	Trough 9 = 1.6%
- outlet	99.2	102.2	<0	100.8	102.1	<0	Trough 12 = 1.5%
- mean	100.2	102.0	<0	101.2	102.1	<0	Mean = 1.6%

* Values shown in Table 5 have been derived from Tables 1 and 2.

Table 6. Seawater challenge test samples.

	Length (cm)		Weight (g)		Condition Coefficient		Plasma Sodium (meq/L)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Control TR 6	8.75	0.67	7.01	1.83	1.01	0.04	169.1	5.81
Aerated TR 12	8.94	0.36	7.46	1.03	1.04	4.38	162.6	6.26
Rearing Channel	9.15	1.16	7.92	2.68	.98	0.04	164.7	4.36

n = 20

Appendix 1. Yolk Reserve Analysis Data

Fry from each trough were sampled at ponding (Feb. 18). These fry were preserved in 5% formalin for subsequent yolk reserve analysis. Individual "preserved" alevins were weighed to obtain the "wet weight", W. Removal of the yolk material allowed measurement of the embryo weight and calculation of the wet embryo to alevin weight ratio. The means and standard deviations of these values are tabled on the next page. The mean dry embryo weight ($\overline{E}$) and the mean dry yolk weight ($\overline{Y}$) have also been displayed. The dry embryo to alevin weight ratio has simply been calculated from these mean values $\overline{E} / (\overline{E}+\overline{Y}) \times 100\%$.

Appendix 1.

Initial Fry Development Data

Date	Trough	N	$\bar{L}$	SD	$\bar{W}$	SD	$\bar{E}$	SD
Feb 18	C 3	15	36.9	1.36	459.8	45.56	61.67	5.93
	A 9	16	37.9	1.32	500.6	64.37	67.06	8.42
	C 6	15	37.9	.89	496.6	43.54	63.80	4.50
	A 12	15	37.3	.81	498.2	55.08	67.73	7.38
Mar 1	C 3	15	38.4	.84	522.8	49.91	76.33	8.26
	A 9	15	39.6	.76	587.5	50.14	87.27	8.28
	C 6	15	38.6	1.01	522.4	47.14	77.80	8.17
	A 12	15	38.0	1.28	482.8	71.23	70.13	10.43

Date	Trough	$\bar{Y}$	SD	$\frac{\bar{E}}{\bar{E}+\bar{Y}} \times 100\%$	KD	SD
Feb 18	C 3	13.33	7.79	82.22	2.0885	.0486
	A 9	17.13	7.12	79.65	2.0893	.0517
	C 6	19.13	7.62	76.93	2.0877	.0342
	A 12	19.73	6.97	77.44	2.1184	.0512
Mar 1	C 3	8.40	6.03	90.00	2.0958	.0506
	A 9	11.73	7.43	88.15	2.1131	.0303
	C 6	6.07	3.08	92.76	2.0809	.0225
	A 12	7.47	4.30	90.37	2.0575	.0418

Date	Trough	Wet Embryo to Alevin Ratio x 100%	SD
Feb 18	C 3	92.1	5.52
	A 9	89.2	2.33
	C 6	88.9	2.27
	A 12	89.2	2.03
Mar 1	C 3	93.9	1.92
	A 9	93.4	2.01
	C 6	94.9	1.23
	A 12	94.3	1.39

$\bar{N}$ = number of fish sampled
$\bar{L}$ = mean length (mm)
SD = standard deviation of preceding value
$\bar{W}$ = mean total weight (mg) (wet)
$\bar{E}$ = mean dry embryo weight (mg)
$\bar{Y}$ = mean dry yolk weight (mg)
KD = developmental index

C = Control Trough
A = Aerated Trough

Appendix 2. Length/Weights, Condition Coefficients and Daily Food Rations.

Appendix 2 (con'd)

DATA: LENGTH - WEIGHT - FEED

Control-Trough No. 3

(Sample Size=100)

Weeks After Ponding	Length mm		Weight g		K		Food - Daily g				
	Mean	SD	Mean	SD	Mean	SD	Mash	1/32	3/64	1/16	3/32
1	38.38	1.18	0.42	0.06	0.74	.087	710	100			
2	40.58	1.29	0.46	0.05	0.69	.056	620	265			
3	40.08	1.25	0.52	0.07	0.80	.053	400	600			
4							300	833			
5	42.35	1.63	0.66	0.09	0.87	.051		1 334			
6								1 412			
7	46.02	2.03	0.89	0.14	0.91	.076		894	894		
8	48.69	2.41	1.15	0.19	0.98	.062			845*		
9									932	113	
10	54.13	3.21	1.71	0.35	1.06	.097			390	900	
11									300	1 000	
12	63.94	3.58	2.87	0.52	1.09	.068				300	1 138
13										300	1 486
14	73.15	4.69	4.40	1.01	1.11	.104				200	1 862
15	76.98	5.23	4.71	1.01	1.02	.101					2 475
16	87.08	5.00	7.07	1.22	1.06	.082					2 755
17	91.15	5.51	8.40	1.52	1.10	.073					3 809

*Trough Population Reduced from 50 000 to 15 000.

Appendix 2 (con'd)

DATA: LENGTH - WEIGHT - FEED

Control-Trough No. 6

(Sample Size = 100)

Weeks After Ponding	Length mm		Weight g		K		Food - Daily g				
	Mean	SD	Mean	SD	Mean	SD	Mash	1/32	3/64	1/16	3/32
1	38.50	1.21	0.44	0.05	0.77	.056	708	125			
2	38.98	1.14	0.47	0.05	0.79	.048	550	340			
3	40.16	1.28	0.53	0.06	0.82	.055	300	700			
4							264	850			
5	42.63	1.84	0.67	0.10	0.86	.049		1 332			
6								1 589	400		
7	45.65	2.08	0.87	0.13	0.91	.061		1 034	690		
8	48.66	2.30	1.13	0.19	0.97	.063			836*		
9									932	113	
10	54.63	2.79	1.76	0.33	1.07	.114			240	1 100	
11									200	1 100	
12	63.98	3.40	2.85	0.49	1.08	.110				357	1 071
13										300	1 486
14	74.80	4.37	4.68	0.86	1.11	.061				200	1 995
15	79.17	5.59	5.35	1.14	1.06	.165					2 579
16	86.96	5.05	7.68	1.46	1.16	.105					3 116
17	91.17	6.55	8.71	2.25	1.12	.127					4 140

*Trough Population Reduced from 50 000 to 15 000.

Appendix 2 (con'd)

DATA: LENGTH - WEIGHT - FEED

aerated - Trough No. 9

(Sample Size = 100)

Weeks After Ponding	Length mm		Weight g		K		Food - Daily g				
	Mean	SD	Mean	SD	Mean	SD	Mash	1/32	3/64	1/16	3/32
1	39.07	1.55	0.55	0.05	0.75	.061	710	145			
2	39.35	1.37	0.49	0.06	0.79	.050	730	400			
3	40.25	1.44	0.53	0.07	0.82	.064	300	700			
4							300	818			
5	42.81	1.78	0.69	0.10	0.87	.063		1 198			
6								1 236	200		
7	47.09	2.08	0.96	0.14	0.92	.088		638	1 276		
8	49.02	2.55	1.18	0.19	0.99	.051			791	75*	
9									932	113	
10	56.07	2.98	1.92	0.34	1.08	.077			240	1 200	
11									100	1 300	
12	63.80	3.70	2.93	0.58	1.11	.069				311	1 172
13										300	1 562
14	75.03	3.71	4.87	0.82	1.14	.063				200	2 115
15	77.67	5.66	4.93	1.24	1.03	.130					2 635
16	89.01	5.24	7.62	1.36	1.07	.093					2 856
17	92.28	6.33	9.12	2.05	1.14	.079					4 172

*Trough Population Reduced from 50 000 to 15 000.

Appendix 2 (con'd)

DATA: LENGTH - WEIGHT - FEED

aerated - Trough No. 12

(Sample Size - 100)

Weeks After Ponding	Length mm		Weight g		K		Food - Daily g				
	Mean	SD	Mean	SD	Mean	SD	Mash	1/32	3/64	1/16	3/32
1	38.91	1.11	0.45	0.05	0.75	.050	747	121			
2	39.16	1.24	0.48	0.06	0.80	.052	600	310			
3	40.12	1.11	0.53	0.06	0.83	.062	255	767			
4							235	900			
5	43.09	1.61	0.71	0.09	0.88	.056		1 439			
6								1 339	200		
7	46.38	2.20	0.92	0.15	0.92	.069		744	1 117		
8	49.28	2.14	1.19	0.20	0.99	.102			871*		
9									932	113	
10	55.91	2.36	1.93	0.31	1.10	.079			140	1 300	
11									100	1 300	
12	63.82	3.28	2.82	0.50	1.08	.092				271	1 160
13										300	1 513
14	73.14	5.50	4.57	0.97	1.16	.285				200	1 978
15	75.44	6.56	4.72	1.23	1.08	.151					2 529
16	86.77	4.57	7.77	1.25	1.18	.090					2 708
17	91.32	5.63	8.72	1.67	1.13	.062					4 259

*Trough Population Reduced from 50 000 to 15 000.

Appendix 2(con'd)

DATA: LENGTH - WEIGHT - FEED

Rearing Channel

(Sample Size = 100)

Weeks After Ponding	Length mm		Weight g		K.		Food - Daily g				
	Mean	SD	Mean	SD	Mean	SD	Mash	1/32	3/64	1/16	3/32
6	48.16	3.45	1.05	0.26	0.92	.059		8 967	28 397		
7								11 114	33 342		
8	52.33	3.50	1.46	0.34	1.00	.066		4 792	42 780	23 632 *	
9								5 700	58 286	30 000	
10	57.37	5.02	2.20	0.59	1.14	.070			17 842	112 857	
11									12 000	60 200	48 200
12	65.12	5.76	3.22	0.88	1.14	.059				28 566	114 268
13										8 660	135 660
14	75.10	5.59	4.79	1.13	1.11	.102				7 455	178 926
15	81.76	6.71	5.66	1.37	1.02	.102				14 000	200 193
16	96.28	4.53	10.23	1.58	1.14	.078				14 000	257 874
17	99.96	5.96	11.22	2.17	1.11	.068				14 000	301 128

* 330 000 fry transferred to the Channel from the Burrows pond and the study troughs.

Appendix 3. Disease Investigations.
Random samples of healthy fish and moribund fish were examined by the Diagnostic service on March 24, May 10 and June 17, 1983.

Random sample - case 83084, collected March 24, 1983
- No infectious disease agents detected.
- Externally - normal appearance of cultured fry
- Blood smears
  - all judged to be within the normal range of variability for chinook fry
- Internally - remnants of coagulated yolk material found:

Trough	Coagulated yolk
3	7
6	1
9	0
12	2

- Histology

Trough	Gill structures	Internal organs
3	Slight hypertrophy	Moderate liver vacuolation
6	Slight hypertrophy	Slight liver vacuolation
9	Slight hypertrophy	Normal
12	Normal	Normal

Slight hypertrophy is a common finding among cultured salmonid fry.

Moribund sample
- No infectious disease agents found.
- Samples generally consisted of injured, deformed, emaciated or fish with severe yolk coagulation.

Random sample - case 83170, collected May 10, 1983.
- No infectious disease agents found.
- Externally, all judged to be normal.
- Blood smears.
  - all within the normal range of variability for fry.
- Hematocrit values

Trough	Hct %	Coagulated yolk
3	42.0	1
6	44.5	1
9	39.2	1
12	43.0	4

- Internal, normal except for trace amounts of coagulated yolk material.
- Histology

Trough	Gill structures	Internal Organs
3	Normal	Varying degrees of liver vacuolation, otherwise normal
6	Slight Hypertrophy	Varying degrees of liver vacuolation, otherwise normal
9	Normal	Normal
12	Normal	Normal

Moribund sample
- Not collected.

Random sample - case 83228; collected June 17, 1983.
- No infectious disease agents found.
- Externals - normal.
- Blood smears
  - all judged to be within normal range.
- Hematocrit values

Trough	Hct %
3	42.5
6	43.0
9	40.9
12	40.6

- Internals - normal.
- Histology

Trough	Gill structures	Internal organs
3	Normal	Normal
6	Normal	Slight liver vacuolation
9	Normal	Normal
12	Normal	Normal

Moribund sample

Trough	
3	3/6 furunculosis, 3/6 severe deformity
6	2/4 furunculosis, 1/4 deformed, 1/4 normal
9	2/2 furunculosis
12	0

Start of an outbreak of furunculosis.

Appendix 4. Mortality Rates.

Weekly mortality rates have been calculated for the experimental troughs and the production rearing channel. The total mortality over the rearing period and the average weekly mortality rates have also been calculated.

DATA: MORTALITY

Weeks After Ponding	Control-Trough No. 3			Control-Trough No. 6			aerated-Trough No. 9			aerated-Trough No. 12			Production Channel		
	No./Wk.	Tot. Pop.	%/Wk.	No./Wk.	Tot. Pop.	%/Wk.	No./Wk.	Tot. Pop.	%/Wk.	No./Wk.	Tot. Pop.	%/Wk.	No./Wk.	Tot. Pop.	%/Wk.
2	35	50 620	.069	24	49 767	.048	28	49 961	.056	30	50 734	.059			
3	37	50 583	.073	34	49 733	.068	22	49 939	.044	26	50 708	.051	First fish transferred to rearing channel during week 3.		
4	45	50 538	.089	23	49 710	.046	15	49 924	.030	39	50 669	.077			
5	113	50 425	.224	59	49 651	.119	33	49 891	.066	41	50 628	.081			
6	196	50 229	.390	104	49 547	.210	43	49 848	.086	61	50 567	.121	.384	889 130	.023
7	233	49 996	.466	167	49 380	.338	68	49 780	.136	82	50 485	.162	280	880 850	.031
8	56	14 967	.374	36	14 983	.240	18	14 991	.120	28	14 989	.187	645	1 318 615	.049
9	95	14 872	.638	79	14 904	.530	35	14 956	.234	23	14 966	.154	2 742	1 315 873	.208
10	90	14 782	.609	103	14 801	.695	43	14 913	.288	26	14 940	.174	4 687	1 311 266	.351
11	44	14 738	.299	66	14 735	.447	17	14 896	.114	15	14 925	.101	6 602	1 304 664	.506
12	44	14 694	.300	43	14 692	.292	21	14 875	.141	14	14 911	.094	4 479	1 300 185	.345
13	49	14 645	.335	40	14 652	.273	14	14 861	.094	14	14 997	.094	3 167	1 297 018	.244
14	43	14 602	.294	39	14 613	.267	11	14 850	.074	12	14 885	.081	4 089	1 292 929	.316
15	21	14 581	.147	14	14 599	.095	12	14 838	.080	4	14 881	.026	1 167	1 100 996	.106
16	20	14 562	.137	8	14 572	.056	9	14 799	.061	9	14 916	.061	890	1 100 156	.081
TOTAL %			4.444			3.724			1.624			1.823			2.28
AVERAGE WEEKLY %			0.296			0.248			0.108			0.102			0.206

Appendix 5. Fork Lengths of Mortalities.

From week 10 to the end of the study all the mortalities occurring on one day of each week were collected and preserved in 5% buffered formalin. The lengths of individual dead fish are shown below. These lengths are contrasted with the average length ($\bar{L}$) of healthy fish in the trough. To emphasize the small size of the dead fish, the length of healthy fish at 1 standard deviation ($\bar{L}$-S) and 2 standard deviations ($\bar{L}$-2S) below the mean have also been shown.

		Mean Length $\bar{L}$ of Healthy Fish (mm)			
Date 1983	Trough No.	$\bar{L}$	$\bar{L}$-S	$\bar{L}$-2S	Lengths of individual dead fish.
Apr. 29	3	56.93	53.62	50.31	41.5, 41.0, 49.5, 45.0, 47.5, 43.5, 40.0, 44.0, 49.5, 47.0, 52.5
	6	57.30	54.34	51.38	49.0, 51.0, 45.0, 48.0, 50.0, 47.5, 44.5, 50.0
	9	58.28	55.10	51.92	38.5, 50.5, 57.0, 42.5
	12	58.17	55.55	52.93	48.5, 48.0, 45.0, 49.0
May 11	3	65.26	61.52	57.78	51.5, 43.0, 47.5, 42.0, 43.0, 45.0
	6	65.52	61.98	58.44	44.0, 54.0, 49.0, 44.0
	9	65.40	61.70	58.00	58.0
	12	65.15	61.55	57.95	42.0, 40.5
May 17	3	69.20	64.99	60.78	43.5, 42.0, 40.0, 41.0, 43.0, 42.5, 45.0, 42.5
	6	70.16	66.21	62.26	58.5, 56.0, 62.0, 47.0, 44.5, 46.0
	9	70.22	66.50	62.79	54.0
	12	69.15	64.60	60.05	45.0, 53.5, 43.5
May 24	3	73.69	68.92	64.15	65.5, 44.0, 43.5, 44.0, 45.0, 42.0, 47.5, 44.5
	6	75.42	70.88	66.34	44.0, 45.0, 70.5, 46.0, 46.0, 45.0, 48.5, 42.5, 44.5
	9	75.41	71.42	67.43	48.0, 48.0, 45.5
	12	73.47	67.82	62.14	43.0, 67.5
May 31	3	77.70	72.49	67.28	63.0, 45.0, 45.5, 46.0
	6	79.73	74.18	68.63	44.0, 68.5, 81.5
	9	84.15	78.73	73.31	43.0, 56.0, 48.0, 77.5
	12	76.29	69.88	63.47	69.5
June 7	6	83.62	78.34	73.06	42.5, 66.5
	12	81.91	76.49	71.07	71.5, 73.0
June 14	3	87.66	82.59	77.52	72.5, 79.0, 72.5
	6	87.56	82.30	77.04	48.0
	9	89.48	84.08	78.68	71.5, 50.5

Appendix 6. Water Quality Sampling.

Weekly water sampling included measurement of: gas supersaturation levels, pH, ammonia-N and water flow. ΔP, barometric pressure, dissolved oxygen concentration and water temperature have been used to calculate the remaining gas characteristics in the appendix. The "nitrogen saturation concentration" and "oxygen saturation concentration" values represent the gas concentrations at equilibrium (100% saturation) at the specified water temperature and barometric pressure.

Appendix 6 (con'd)

DATA: CHEMICAL - PHYSICAL

Week No. 2

1983 02 28

Sample Site:		1	2	3	4	5	6	7	8
ΔP	(mm Hg)	39	10	11	3	17	1	13	40
Barometric Pressure	(mm Hg)	742	742	742	742	741	741	742	742
Dissolved O_2 Conc.	(mg/L)	12.53	12.18	12.27	11.35	11.23	10.26	11.27	-
Water Temperature	(°C)	5.8	5.7	5.8	6.0	6.0	6.0	6.0	5.8
N_2 Saturation Conc.	(mg/L)	20.21	20.25	20.21	20.11	20.08	20.08	20.11	-
O_2 Saturation Conc.	(mg/L)	12.19	12.22	12.19	12.13	12.11	12.11	12.13	-
Total Gas Pressure	(%)	105.3	101.4	101.5	100.4	102.3	100.1	101.8	105.4
N_2 as % of Saturation	(%)	106.0	101.9	101.8	102.3	104.9	104.3	104.2	-
O_2 as % of Saturation	(%)	102.8	99.7	100.7	93.6	92.7	84.7	92.9	-
Dissolved N_2 Conc.	(mg/L)	21.42	20.63	20.56	20.57	21.07	20.94	20.95	-
pH		7.19	7.31	7.35	7.18	7.12	7.21	7.11	-
Ammonia	(μg NH_3-N/L)	0	0	0	4	7	20	7	-
Water Flow	(L/min)	-	103	97	103	96	97	98	-

Appendix 6(con'd)

DATA: CHEMICAL - PHYSICAL

Week No. 3

1983 03 11

Sample Site:		1	2	3	4	5	6	7	8
ΔP	(mm Hg)	38	13	10	5	26	6	27	42
Barometric Pressure	(mm Hg)	747	748	748	747	747	747	747	746
Dissolved O_2 Conc.	(mg/L)	12.81	12.1	12	11.39	11.78	11.59	11.86	-
Water Temperature	(°C)	5.9	5.85	5.9	6.0	6.0	6.0	6.0	6.0
N_2 Saturation Conc.	(mg/L)	20.29	20.35	20.32	20.25	20.25	20.25	20.25	-
O_2 Saturation Conc.	(mg/L)	12.24	12.27	12.26	12.21	12.21	12.21	12.21	-
Total Gas Pressure	(%)	105.1	101.8	101.4	100.7	103.5	100.8	103.7	105.7
N_2 as % of Saturation	(%)	105.3	102.6	102.3	102.7	105.4	102.4	105.4	-
O_2 as % of Saturation	(%)	104.7	98.6	97.9	93.3	96.5	94.9	97.1	-
Dissolved N_2 Conc.	(mg/L)	21.37	20.88	20.79	20.79	21.35	20.74	21.34	-
pH		7.17	7.25	7.32	7.19	7.12	7.21	7.12	-
Ammonia	(μg NH_3-N/L)	10	1	1	4	3	4	3	-
Water Flow	(L/min)	-	255	293	255	285	293	231	-

Appendix 6 (con'd)

DATA: CHEMICAL - PHYSICAL

Week No. 4

1983 03 18

Sample Site:		1	2	3	4	5	6	7	8
ΔP	(mm Hg)	44	13	11	2	31	0	33	55
Barometric Pressure	(mm Hg)	746	746	746	746	746	746	746	745
Dissolved O_2 Conc.	(mg/L)	12.89	12.08	12.04	10.90	11.68	10.99	11.39	-
Water Temperature	(°C)	6.0	5.9	5.95	6.3	6.45	6.35	6.6	6.75
N_2 Saturation Conc.	(mg/L)	20.22	20.27	20.24	20.08	20.01	20.06	19.94	-
O_2 Saturation Conc.	(mg/L)	12.19	12.22	12.21	12.10	12.05	12.08	12.01	-
Total Gas Pressure	(%)	106.0	101.8	101.5	100.3	104.2	100.0	104.5	107.5
N_2 as % of Saturation	(%)	106.1	102.6	102.3	103.0	106.2	102.5	107.1	-
O_2 as % of Saturation	(%)	105.7	98.8	98.6	90.1	96.9	90.9	94.9	-
Dissolved N_2 Conc.	(mg/L)	21.45	20.79	20.71	20.68	21.24	20.55	21.35	-
pH		7.12	7.31	7.32	7.02	7.06	7.11	7.02	-
Ammonia	(μg NH_3-N/L)	0	1	0	11	4	24	14	-
Water Flow	(L/min)	-	196	182	196	169	182	164	-

Appendix 6 (con'd)

DATA: CHEMICAL - PHYSICAL

Week No. 5

1983 03 25

Sample Site:		1	2	3	4	5	6	7	8
ΔP	(mm Hg)	42	13	12	3	26	1	25	47
Barometric Pressure	(mm Hg)	749	749	749	749	749	750	748	749
Dissolved O_2 Conc.	(mg/L)	12.24	12.12	12.08	11.15	11.21	11.37	11.37	-
Water Temperature	(°C)	6.5	6.4	6.45	6.7	6.9	6.8	6.9	6.8
N_2 Saturation Conc.	(mg/L)	20.07	20.11	20.09	19.97	19.88	19.95	19.85	-
O_2 Saturation Conc.	(mg/L)	12.09	12.12	12.10	12.03	11.97	12.01	11.95	-
Total Gas Pressure	(%)	105.7	101.8	101.6	100.4	103.5	100.1	103.4	106.3
N_2 as % of Saturation	(%)	106.9	102.3	102.1	102.5	106.2	101.6	105.6	-
O_2 as % of Saturation	(%)	101.3	100.0	99.8	92.7	93.7	94.7	95.1	-
Dissolved N_2 Conc.	(mg/L)	21.45	20.57	20.52	20.47	21.11	20.28	20.97	-
pH		7.19	7.36	7.37	7.16	7.05	7.15	7.06	-
Ammonia	(μg NH_3-N/L)	0	0	0	27	35	27	38	-
Water Flow	(L/min)	-	200	194	200	197	194	185	-

Appendix 6 (con'd)

DATA: CHEMICAL - PHYSICAL

Week No. 6 1983 03 31

Sample Site:		1	2	3	4	5	6	7	8
ΔP	(mm Hg)	33	12	11	3	19	3	19	-
Barometric Pressure	(mm Hg)	752	753	753	753	753	753	753	-
Dissolved O_2 Conc.	(mg/L)	12.37	12.20	12.18	11.47	11.51	11.61	11.57	-
Water Temperature	(°C)	6.2	6.15	6.15	6.2	6.35	6.2	6.3	7.2
N_2 Saturation Conc.	(mg/L)	20.29	20.34	20.34	20.31	20.24	20.31	20.27	-
O_2 Saturation Conc.	(mg/L)	12.23	12.26	12.26	12.24	12.20	12.24	12.21	-
Total Gas Pressure	(%)	104.4	101.6	101.5	100.4	102.6	100.4	102.6	-
N_2 as % of Saturation	(%)	105.3	102.2	102.1	102.2	104.8	101.9	104.7	-
O_2 as % of Saturation	(%)	101.2	99.5	99.4	93.7	94.4	94.8	94.7	-
Dissolved N_2 Conc.	(mg/L)	21.37	20.79	20.76	20.77	21.21	20.71	21.21	-
pH		7.15	7.31	7.31	7.12	7.08	7.11	7.03	-
Ammonia	(μg NH_3-N/L)	3	4	4	33	27	30	27	-
Water Flow	(L/min)	-	293	300	293	250	300	222	-

Appendix 6 (con'd)

DATA: CHEMICAL - PHYSICAL

Week No. 7

1983 04 08

Sample Site:		1	2	3	4	5	6	7	8
ΔP	(mm Hg)	37	8	5	-11	21	-6	21	47
Barometric Pressure	(mm Hg)	755	754	753	753	753	753	753	752
Dissolved O_2 Conc.	(mg/L)	12.30	12.06	12.22	11.07	11.31	11.09	11.31	-
Water Temperature	(°C)	6.65	6.5	6.7	7.0	7.4	7.2	7.4	7.6
N_2 Saturation Conc.	(mg/L)	20.16	20.20	20.08	19.94	19.76	19.85	19.76	-
O_2 Saturation Conc.	(mg/L)	12.14	12.17	12.09	12.00	11.88	11.94	11.88	-
Total Gas Pressure	(%)	105.0	101.1	100.7	98.5	102.8	99.2	102.8	106.3
N_2 as % of Saturation	(%)	106.0	101.6	100.6	100.2	104.9	100.9	104.9	-
O_2 as % of Saturation	(%)	101.3	99.1	101.1	92.2	95.2	92.9	95.2	-
Dissolved N_2 Conc.	(mg/L)	21.36	20.53	20.20	19.99	20.72	20.03	20.72	-
pH		7.20	7.33	7.36	7.12	7.04	7.14	7.01	-
Ammonia	(μg NH_3-N/L)	5	6	6	37	54	40	54	-
Water Flow	(L/min)	-	300	293	300	255	293	240	-

Appendix 6 (con'd)

DATA: CHEMICAL - PHYSICAL

Week No. 8

1983 04 15

Sample Site:		1	2	3	4	5	6	7	8
ΔP	(mm Hg)	45	13	9	7	37	5	40	58
Barometric Pressure	(mm Hg)	757	758	758	758	759	757	756	756
Dissolved O_2 Conc.	(mg/L)	12.08	11.68	11.88	11.39	11.43	11.27	11.15	-
Water Temperature	(°C)	7.6	7.6	7.8	8.1	8.4	8.2	8.6	8.6
N_2 Saturation Conc.	(mg/L)	19.77	19.80	19.71	19.58	19.47	19.51	19.31	-
O_2 Saturation Conc.	(mg/L)	11.89	11.90	11.84	11.76	11.69	11.71	11.58	-
Total Gas Pressure	(%)	106.0	101.7	101.2	100.9	104.9	100.7	105.4	107.8
N_2 as % of Saturation	(%)	107.2	102.7	101.5	102.1	106.9	101.9	107.8	-
O_2 as % of Saturation	(%)	101.6	98.1	100.3	96.9	97.8	96.2	96.3	-
Dissolved N_2 Conc.	(mg/L)	21.20	20.34	20.00	19.98	20.81	19.88	20.81	-
pH		7.34	7.46	7.46	7.38	7.24	7.34	7.27	-
Ammonia	(μg NH_3-N/L)	11	13	13	25	27	36	30	-
Water Flow	(L/min)	-	279	286	279	240	286	235	-

Appendix 6 (con'd)

DATA: CHEMICAL - PHYSICAL

Week No. 9

1983 04 22

Sample Site:		1	2	3	4	5	6	7	8
ΔP	(mm Hg)	40	9	7	1	29	0	30	51
Barometric Pressure	(mm Hg)	749	749	749	749	749	749	749	749
Dissolved O_2 Conc.	(mg/L)	11.42	11.35	11.27	10.78	10.95	10.78	10.28	-
Water Temperature	(°C)	8.8	8.9	9.0	9.15	9.25	9.2	9.35	9.35
N_2 Saturation Conc.	(mg/L)	19.04	19.00	18.96	18.90	18.85	18.87	18.81	-
O_2 Saturation Conc.	(mg/L)	11.42	11.39	11.36	11.32	11.30	11.31	11.27	-
Total Gas Pressure	(%)	105.4	101.2	101.0	100.1	103.9	100.0	104.1	106.9
N_2 as % of Saturation	(%)	106.9	101.7	101.5	101.5	105.8	101.3	107.5	-
O_2 as % of Saturation	(%)	100.0	99.6	99.2	95.2	96.9	95.3	91.2	-
Dissolved N_2 Conc.	(mg/L)	20.35	19.32	19.24	19.18	19.95	19.12	20.22	-
pH		7.28	7.47	7.51	7.26	7.25	7.37	7.25	-
Ammonia	(μg NH_3-N/L)	14	17	15	36	42	37	61	-
Water Flow	(L/min)	-	286	286	286	245	286	222	-

Appendix 6 (con'd)

DATA: CHEMICAL - PHYSICAL

Week No. 10

1983 04 29

Sample Site:		1	2	3	4	5	6	7	8
ΔP	(mm Hg)	40	7	6	0	23	6	29	69
Barometric Pressure	(mm Hg)	747	749	749	749	749	749	749	746
Dissolved O_2 Conc.	(mg/L)	10.99	11.23	11.11	10.66	10.18	10.38	10.58	-
Water Temperature	(°C)	9.4	9.5	9.6	9.5	9.85	9.6	10.1	10.9
N_2 Saturation Conc.	(mg/L)	18.74	18.75	18.71	18.75	18.61	18.71	18.51	-
O_2 Saturation Conc.	(mg/L)	11.23	11.23	11.20	11.23	11.14	11.20	11.07	-
Total Gas Pressure	(%)	105.4	101.0	100.8	100.0	103.1	100.8	103.9	109.4
N_2 as % of Saturation	(%)	107.5	101.2	101.3	101.4	106.3	103.0	106.2	-
O_2 as % of Saturation	(%)	97.9	100.0	99.2	94.9	91.4	92.7	95.6	-
Dissolved N_2 Conc.	(mg/L)	20.14	18.98	18.95	19.01	19.77	19.27	19.65	-
pH		7.41	7.64	7.67	7.48	7.30	7.45	7.25	-
Ammonia	(μg NH_3-N/L)	32	26	30	58	87	98	86	-
Water Flow	(L/min)	-	261	267	261	235	267	218	-

Appendix 6 (con't)

DATA: CHEMICAL - PHYSICAL

Week No. 11

1983 05 06

Sample Site:		1	2	3	4	5	6	7	8
ΔP	(mm Hg)	31	7	5	-2	16	-5	16	40
Barometric Pressure	(mm Hg)	747	747	747	747	747	747	746	746
Dissolved O_2 Conc.	(mg/L)	10.87	11.03	11.03	10.26	10.09	10.22	10.16	-
Water Temperature	(°C)	9.5	9.4	9.45	9.6	9.75	9.6	9.8	10.15
N_2 Saturation Conc.	(mg/L)	18.70	18.74	18.72	18.66	18.60	18.66	18.55	-
O_2 Saturation Conc.	(mg/L)	11.20	11.23	11.21	11.17	11.13	11.17	11.10	-
Total Gas Pressure	(%)	104.2	101.0	100.7	99.7	102.2	99.3	102.2	105.4
N_2 as % of Saturation	(%)	106.1	101.7	101.3	101.9	105.3	101.5	105.1	-
O_2 as % of Saturation	(%)	97.1	98.3	98.4	91.8	90.6	91.5	91.5	-
Dissolved N_2 Conc.	(mg/L)	19.85	19.06	18.97	19.01	19.58	18.93	19.49	-
pH		7.32	7.53	7.47	7.34	7.27	7.30	7.23	-
Ammonia	(μg NH_3-N/L)	28	23	26	69	75	77	80	-
Water Flow	(L/min)	-	300	293	300	300	293	293	-

Appendix 6 (con'd)

DATA: CHEMICAL - PHYSICAL

Week No. 12

1983 05 13

Sample Site:		1	2	3	4	5	6	7	8
ΔP	(mm Hg)	42	9	7	-6	14	-11	14	49
Barometric Pressure	(mm Hg)	753	753	753	753	753	753	752	751
Dissolved O_2 Conc.	(mg/L)	10.36	10.78	10.66	9.69	9.18	9.22	9.06	-
Water Temperature	(°C)	11.05	10.7	10.75	11.0	11.15	11.20	11.10	11.70
N_2 Saturation Conc.	(mg/L)	18.23	18.36	18.34	18.25	18.19	18.17	18.18	-
O_2 Saturation Conc.	(mg/L)	10.88	10.97	10.96	10.90	10.86	10.84	10.86	-
Total Gas Pressure	(%)	105.7	101.2	100.9	99.2	101.9	98.5	101.9	106.6
N_2 as % of Saturation	(%)	108.5	102.0	102.0	102.0	106.5	102.1	106.8	-
O_2 as % of Saturation	(%)	95.2	98.3	97.3	88.9	84.6	85.0	83.5	-
Dissolved N_2 Conc.	(mg/L)	19.77	18.74	18.70	18.60	19.38	18.56	19.42	-
pH		7.26	7.44	7.49	7.10	7.12	7.13	7.06	-
Ammonia	(μg NH_3-N/L)	49	44	45	127	127	144	145	-
Water Flow	(L/min)	-	245	231	245	273	231	255	-

Appendix 6 (con'd)

DATA: CHEMICAL - PHYSICAL

Week No. 13

1983 05 20

Sample Site:		1	2	3	4	5	6	7	8
ΔP	(mm Hg)	31	3	4	-11	1	-16	4	41
Barometric Pressure	(mm Hg)	756	756	756	756	756	756	756	756
Dissolved O_2 Conc.	(mg/L)	9.97	10.78	10.72	8.98	9.20	9.57	8.80	-
Water Temperature	(°C)	10.90	10.70	10.70	10.80	11.00	10.75	11.10	11.50
N_2 Saturation Conc.	(mg/L)	18.36	18.44	18.44	18.40	18.32	18.42	18.28	-
O_2 Saturation Conc.	(mg/L)	10.96	11.02	11.02	10.99	10.94	11.00	10.91	-
Total Gas Pressure	(%)	104.2	100.4	100.5	98.5	100.1	97.9	100.5	105.5
N_2 as % of Saturation	(%)	107.7	101.1	101.4	103.0	104.4	100.8	105.9	-
O_2 as % of Saturation	(%)	90.9	97.9	97.3	81.7	84.1	87.0	80.6	-
Dissolved N_2 Conc.	(mg/L)	19.77	18.64	18.70	18.96	19.13	18.56	19.35	-
pH		7.36	7.59	7.62	7.26	7.05	7.28	7.01	-
Ammonia	(μg NH_3-N/L)	51	54	53	169	183	199	185	-
Water Flow	(L/min)	-	240	245	240	273	245	255	-

Appendix 6 (con'd)

DATA: CHEMICAL - PHYSICAL

Week No. 14 1983 05 27

Sample Site:		1	2	3	4	5	6	7	8
ΔP	(mm Hg)	34	1	0	-16	-6	-16	4	45
Barometric Pressure	(mm Hg)	750	750	750	750	750	750	750	751
Dissolved O_2 Conc.	(mg/L)	9.08	10.24	10.22	6.95	6.75	7.68	6.89	-
Water Temperature	(°C)	12.30	12.50	12.50	12.75	13.10	12.85	13.30	13.90
N_2 Saturation Conc.	(mg/L)	17.68	17.61	17.61	17.52	17.39	17.48	17.32	-
O_2 Saturation Conc.	(mg/L)	10.53	10.48	10.48	10.42	10.34	10.40	10.30	-
Total Gas Pressure	(%)	104.6	100.1	100.0	97.8	99.2	97.8	100.5	106.1
N_2 as % of Saturation	(%)	109.5	100.8	100.7	106.1	108.2	104.2	109.5	-
O_2 as % of Saturation	(%)	86.2	97.7	97.5	66.7	65.3	73.8	66.9	-
Dissolved N_2 Conc.	(mg/L)	19.36	17.75	17.73	18.59	18.82	18.22	18.96	-
pH		6.99	7.42	7.37	6.83	6.84	6.90	6.83	-
Ammonia	(μg NH_3-N/L)	70	64	73	272	246	315	286	-
Water Flow	(L/min)	-	169	226	169	255	226	222	-

Appendix 6 (con'd)

DATA: CHEMICAL - PHYSICAL

Week No. 15

1983 06 03

Sample Site:		1	2	3	4	5	6	7	8
ΔP	(mm Hg)	32	8	9	-34	0	-32	1	-
Barometric Pressure	(mm Hg)	755	755	756	755	754	754	754	-
Dissolved O_2 Conc.	(mg/L)	9.43	10.44	10.26	8.05	8.31	7.56	7.86	-
Water Temperature	(°C)	11.85	12.10	12.40	12.90	12.90	12.90	12.95	-
N_2 Saturation Conc.	(mg/L)	-	-	-	-	-	-	-	-
O_2 Saturation Conc.	(mg/L)	-	-	-	-	-	-	-	-
Total Gas Pressure	(%)	104.3	101.1	101.2	95.4	100.0	95.7	100.1	-
N_2 as % of Saturation	(%)	108.7	101.9	102.4	100.4	105.5	101.9	106.7	-
O_2 as % of Saturation	(%)	88.0	98.0	96.9	77.0	79.6	72.5	75.4	-
Dissolved N_2 Conc.	(mg/L)	19.52	18.22	18.21	17.64	18.51	17.86	18.69	-
pH		7.08	7.35	7.38	6.84	6.81	6.95	6.77	-
Ammonia	(μg NH_3-N/L)	57	54	47	238	190	194	216	-
Water Flow	(L/min)	-	207	279	207	267	279	250	-

Appendix 6 (con'd)

DATA: CHEMICAL - PHYSICAL

Week No. 16

1983 06 10

Sample Site:		1	2	3	4	5	6	7	8
ΔP	(mm Hg)	33	5	3	-28	0	-27	-2	-
Barometric Pressure	(mm Hg)	745	745	745	745	745	745	745	-
Dissolved O_2 Conc.	(mg/L)	9.51	9.83	9.87	7.60	7.80	7.89	7.41	-
Water Temperature	(°C)	13.70	13.60	13.70	13.80	13.80	13.80	13.80	-
N_2 Saturation Conc.	(mg/L)	-	-	-	-	-	-	-	-
O_2 Saturation Conc.	(mg/L)	-	-	-	-	-	-	-	-
Total Gas Pressure	(%)	104.5	100.7	100.4	96.2	100.0	96.3	99.7	-
N_2 as % of Saturation	(%)	107.4	101.8	101.3	101.8	106.1	101.2	106.8	-
O_2 as % of Saturation	(%)	93.8	96.8	97.4	75.1	77.1	78.0	73.4	-
Dissolved N_2 Conc.	(mg/L)	18.32	17.40	17.28	17.34	18.07	17.24	18.18	-
pH		7.18	7.39	7.40	7.00	6.94	7.03	6.98	-
Ammonia	(μg NH_3-N/L)	24	26	32	188	177	185	205	-
Water Flow	(L/min)	-	364	364	364	414	364	343	-

Appendix 7. Water Temperatures.

A thermograph was located near the inlet to the experimental troughs (site 1 in Fig. 3.). Daily maximum and minimum temperatures have been derived from the thermograph and are tabled below:

TEMPERATURES: MAXIMUM - MINIMUM

(Hatchery Records of Inlet River Water)

	February		March		April		May		June	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	5.7	5.3	5.9	5.2	6.0	6.0	10.0	9.2	13.0	12.2
2	6.7	5.1	6.1	5.4	6.8	6.0	9.7	9.3	12.3	12.1
3	5.5	5.1	6.2	5.7	7.0	6.0	9.8	9.2	12.2	12.0
4	5.5	5.1	6.2	5.6	7.6	6.1	9.7	9.2	12.0	12.2
5	5.2	5.1	6.0	5.5	7.4	6.3	9.9	9.1	12.8	12.4
6	5.2	5.1	5.9	5.9	7.4	6.9	9.8	9.3	13.4	12.7
7	5.5	5.5	5.9	5.6	.4	6.4	9.9	9.2	14.1	13.2
8	5.0	5.0	6.0	5.9	7.4	6.3	9.7	9.2	14.0	13.6
9	5.0	5.0	6.3	5.8	7.1	7.0	9.9	9.2	13.8	13.5
10	5.0	5.0	6.0	5.8	7.1	6.7	10.2	9.6	13.5	13.3
11	5.0	5.0	6.1	5.9	7.3	6.8	10.7	9.8	13.7	13.2
12	5.0	5.0	6.0	6.0	7.6	6.6	10.9	10.1	13.9	13.2
13	5.5	5.5	6.0	5.7	7.9	6.9	10.8	10.1	13.9	13.7
14	6.0	5.0	6.3	5.7	8.0	7.1	10.3	10.1	14.1	13.7
15	5.5	5.0	6.1	5.5	8.2	7.3	10.9	10.1	13.9	13.5
16	6.0	5.0	6.4	5.7	8.3	7.7	10.7	10.5	13.6	13.5
17	5.5	5.5	6.4	5.7	8.6	7.9	10.7	10.2	14.0	13.3
18	5.8	5.5	6.7	5.9	8.8	8.1	11.0	10.1	13.9	13.2
19	5.5	5.5	6.8	5.9	9.4	8.5	11.2	10.8	13.7	13.4
20	5.5	5.0	6.7	6.0	8.8	8.1	11.1	10.9		
21	5.7	5.1	6.8	6.1	8.8	8.1	11.3	10.9		
22	5.7	5.3	6.8	6.2	8.9	8.2	11.2	10.9		
23	5.7	5.5	7.0	6.0	9.0	8.3	12.0	11.0		
24	5.7	5.5	6.9	6.0	8.8	8.3	12.0	11.5		
25	5.6	5.5	6.9	6.0	8.7	8.2	12.2	11.5		
26	5.9	5.4	6.7	6.2	8.9	8.3	12.5	12.0		
27	5.9	5.3	6.7	6.2	9.3	8.2	12.8	12.0		
28	6.0	5.2	6.5	6.5	9.7	8.8	13.0	12.3		
29			6.25	6.0	9.9	9.1	13.0	12.5		
30			6.5	6.0	10.1	9.1	12.8	12.5		
31			6.75	6.0			13.2	12.6		

Appendix 8. Metals Analyses.
Metals analyses were performed on water samples preserved with nitric acid - hence all values should be interpreted as "extractable" concentrations. Hardness is expressed as mg. per liter of $CaCO_3$.

Puntledge River Hatchery - Upper Site

Extractable - mg/L

	1983				
Elements	Feb. 23	Mar. 16	Apr. 6	Apr. 20	May 20
As	<.05	<.05	<.05	<.05	<.05
B	.008	.003	<.001	.018	<.001
Ba	<.001	<.001	<.001	<.001	<.001
Be	<.001	<.001	<.001	<.001	<.001
Cd	<.002	<.002	<.002	<.002	<.002
Co	<.005	<.005	<.005	<.005	<.005
Cr	<.005	<.005	<.005	<.005	<.005
Cu	<.005	<.005	<.005	<.005	<.005
Hg	<.05	<.05	<.05	<.05	<.05
Mn	.003	.003	.002	.003	<.004
Mo	<.005	<.005	<.005	<.005	<.004
Ni	<.02	<.02	<.02	.02	<.02
P	<.05	<.05	<.05	.08	<.05
Pb	<.02	<.02	<.02	<.02	<.02
Sb	<.05	<.05	<.05	<.05	<.05
Se	<.05	<.05	<.05	<.05	<.05
Sn	<.01	<.01	<.01	<.01	<.01
Sr	.008	.008	.008	.008	.008
Ti	<.002	.003	<.002	<.002	<.002
V	<.01	<.01	<.01	<.01	<.01
Zn	<.002	<.002	<.002	<.002	.031
Al	<.05	<.05	<.05	<.05	<.05
Fe	.042	.037	.023	.019	.024
Si	2.3	2.1	2.1	2.0	2.0
Ca	5.2	4.9	5.1	5.1	5.3
Mg	.9	.8	.8	.8	.8
Na	.7	.7	.7	.8	.7
Hardness ($CaCO_3$)					
Ca, Mg	16.8	15.6	16.2	15.9	16.7
Total	17.1	15.8	16.4	16.1	16.8